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Evaluating the Costs and Benefits of Tidal Range Energy Generation

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Evaluating the Costs and Benefits of Tidal Range Energy Generation

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Abstract

Tidal barrages could contribute to mitigating climate change, but their deployment is not without potential welfare costs attributable to the degradation of ecosystem services. Economic valuation of natural resources provides a common metric for quantifying the disparate costs and benefits of barrage construction in a way that provides transparency when trade-offs are considered. However, very little is currently known about the value of environmental impacts associated with tidal barrages.

Using the Taw Torridge estuary in North Devon as a case study, this research proposes an Environmental Benefits Assessment methodology that supports application of the ecosystem services concept to local environmental impact appraisal, and facilitates economic valuation. This methodology is novel in that it evaluates benefits, as opposed to services, and considers a comprehensive suite of benefits in a single assessment: an approach rarely attempted in practice, but essential if ecosystem services approaches are to fully support resource management needs.

The subsequent empirical valuation uses stated preference techniques to examine the different ways people use and value the estuary ecosystem, determine how strongly they rank different costs and benefits of tidal barrages, and elicit willingness to pay (WTP) to reduce the habitat loss resulting from a tidal barrage development. The study provides the first empirical valuation of UK estuarine mudflats, but makes a further contribution to the environmental economics discipline by deploying both contingent valuation and choice experiment methods. Additionally, a novel application of the Analytic Hierarchy Process (AHP) is used to examine the consistency of WTP with expressed preferences for habitat protection in relation to other barrage attributes.

The alternative stated preference techniques result in comparable WTP values and the importance attached to habitat loss (as measured by the AHP) is strongly associated with WTP and also with its scope sensitivity, indicating that WTP is largely driven by environmental preferences.

1 Marine Renewable Energy in the UK

1.1 Introduction

In common with many other countries, energy security issues and climate change are driving the UK Government to support alternative energy sources to replace fossil fuels. An important component of this strategy is the generation of electricity from renewable sources, and a significant contribution to renewables targets could be made by tidal power. This chapter reviews the context and content of UK policy for renewable electricity, and the role of tidal power within it. The motivation for the research, its specific aims and objectives and the structure of the research thesis will also be outlined.

1.2 Drivers of UK Energy Policy

Energy Security

Interest in the generation of energy from non-fossil fuel sources increased considerably following the 1973 oil crisis. Globally, investment by governments in renewable energy research and development rose sharply from 1975 to a peak in 1981, but these budgets had halved again by 1987 (AEA, 2006). The security of energy supply is once again of increasing concern. The UK has been a net importer of gas since 2004, and in 2011, oil imports exceeded production for the first time, a trend which continued in 2012 (DECC, 2013a). North Sea oil production peaked in 1999 (JESS, 2006), and the trend towards regular net imports of crude oil has already begun (DECC, 2009a). This reliance on other producers for its energy supply makes the UK vulnerable to price fluctuations and supply shortages, which may result if regulatory failure, political upheaval or conflict occur in energy producing countries (DTI, 2003), many of which are found in politically unstable parts of the world. Stocks of fossil fuels are also diminishing, but demand for them is increasing with global development. UK Government policy, therefore, is to maintain a reliable supply by obtaining energy from diverse sources, within which renewable energy resources have an important role (DTI, 2003).

Climate Change

Climate change is another driver for the inclusion of non-fossil fuel sources as a specific component of alternative energy policy. Based on the available scientific data and models, the Intergovernmental Panel on Climate Change (IPCC) established under the UN Framework Convention on Climate Change concludes that observed increases in air and ocean temperatures, rising sea level, and widespread melting of ice and snow are unequivocal indicators that the global climate is warming (IPCC, 2007). The IPCC also asserts (with a likelihood rated at more than

90%) that most of the observed increase in global average temperatures is due to the increased atmospheric concentrations of greenhouse gases that have resulted from human activity (IPCC, 2007). Greenhouse gas concentrations increased by 70% in the period 1970 to 2004: fossil fuel use is the primary cause of the increase in atmospheric carbon dioxide and also contributes to the growing methane concentrations (IPCC, 2007).

Several international, regional and national policies have been developed in response to this scientific evidence. The Kyoto Protocol covers the period to 2012, and sets binding targets committing 37 countries, including the UK, to reduce their greenhouse gas emissions (United Nations, 1998). The Doha amendment, agreed in December 2012, brought in a second commitment period up to 2020, although by November 2013 it had only been accepted by four countries (UNFCCC, 2013a). In December 2009, countries of the United Nations Framework Convention on Climate Change met in Copenhagen to debate the next stage of carbon emissions reduction, and the result was the Copenhagen Accord (UNFCCC, 2010). During the Conference of the Parties, 114 countries agreed to the Accord, including the United States, which did not ratify the Kyotol Protocol. The Accord did not set binding carbon emissions reduction targets, but it did propose two Annexes (United Nations, 2010). Under Annex I, developed countries are required to submit their own quantified, economy-wide emissions reduction targets. Developing countries are not required to submit quantified targets, but instead must describe in Annex II the nationally appropriate mitigation actions that will be taken. Forty five developing countries have since submitted their proposed Annex II actions, and 43 countries their Annex I targets, with most countries offer cuts within the range of 5-40% based on the 1990 baseline (UNFCCC, 2013b).

The European Commission has proposed multilateral action, and initially set a target for industrialised countries to reduce their emissions by 15% from the 1990 level by the year 2010 (European Commission, 1997). Renewable energy sources supplied less than 6% of the European Union’s gross inland energy consumption in 1997, but the Commission expected that by 2010 renewables could contribute 1GW of electricity (European Commission, 1997), a target which has been met (World Energy Council, 2009). Targets were also set for individual members states, and that set for the UK in 2001 was to produce 10% of its electricity from renewable sources by 2010 (European Parliament, 2001). This target was not met, as renewables contributed only 6.8% of UK electricity in 2010 (DECC, 2013). European Union greenhouse gas reduction targets have since become more stringent, with 2007 policy calling for an emissions reduction of 30% compared to 1990 emission levels by 2020, and a long-term view of achieving a 60-80% reduction by 2050 (European Parliament, 2007).

The UK Government also has its own national approach to climate change mitigation. The Stern Review concluded that a business-as-usual scenario presented at least a 50% risk that global average temperature rise would exceed 5^{o}C, and that the benefits of decisive mitigation action now outweighed the associated costs (HMT, 2006a,b). In response to this analysis and the international, regional and national drivers, the UK Government has committed to ambitious fossil fuel reduction targets: The 2008 Climate Change Act set legally binding 'carbon budgets', to cut UK emissions by 34% by 2020 and at least 80% by 2050 (HMG, 2009a). Achieving these goals requires new strategies for electricity generation, heat, and transport, and needs demand reduction and improved efficiency as well as new industries and technologies. The strategies that are proposed for low carbon energy over the decade to 2020 also include the construction of four new nuclear power stations, funding four carbon capture and storage demonstration projects, providing every home with a smart meter, providing financial incentives for efficiency and micro-generation, and investing in the world's largest electric car demonstration project (HMG, 2009a). The Government plans to invest £30 billion in the renewable energy sector, to support the development of electrified transport, heat generation from biomass, biogas, solar and heat pumps, and the production of electricity from wind, wave, tidal, hydropower and biomass (HMG, 2009b).

1.3 The Role of Renewable Energy in Electricity Generation

Renewable energy is an attractive prospect because it is not derived from finite sources and its use also lacks the health and pollution effects associated with burning coal, oil and gas, and the toxic waste disposal problems of nuclear power (Rourke et al., 2010a). Also, much more of the energy produced by renewables is converted into the electricity supplied to the consumer. 30% of the energy produced from gas, 25% from coal and 16% from nuclear is used in the generation process, but only 1.5% on average is used for the renewable technologies currently employed in the UK (DECC, 2010a). Renewable energy is also expected to contribute 21% of carbon emission reduction targets by 2050, while nuclear power will account for only 6% of these targets (HMG, 2009b).

Electricity generation is the main focus of the UK renewables strategy, and is predicted to account for 49% of renewable energy usage by 2020, with 30% used for heat and 21% for transport (HMG, 2009b). The Government's target is for 30% of UK electricity to be produced from renewable sources by 2020 (HMG, 2009a), compared to just 12% of heat and 10% of transport energy (HMG, 2009b). Renewable energy supplied 2.5% of UK electricity in 2000 (HMG, 2009b), a share which had increased to 11.3% by 2012 (DECC 2013).

Wind power (both on- and offshore) is the most important renewable energy source utilised in the UK at present, in terms of its contribution to energy supply, the economy and exports (Innovas, 2009). It is expected that two thirds of the 2020 renewable electricity target will be met by wind power (HMG, 2009b). The UK has the largest wind resource in Europe (SDC, 2005), and since 2008 has led the world in terms of installed capacity of offshore wind power, which, at more than 3GW, is sufficient to supply around 1.5 million homes (HMG, 2009b).

Hydropower is another mature renewable energy technology employed in the UK. It is, however, a small sector, and its contribution to UK electricity supply decreased between 1990 and 2000, since when it has supplied a fairly constant 1% of UK electricity (DECC, 2009b). The UK's other renewable energy sources have substantially increased their contribution since 1990, and continue to do so rapidly – wind power alone supplied 20% more electricity in 2009 than in 2008 (DECC, 2010a). Biomass is another small, but growing, sector in electricity production. It is believed that this can be sustainable and without detrimental impact on food production or the wider environment (HMG, 2009b). Solar photovoltaics do not form a significant part of the UK's renewable electricity strategy (HMG, 2009b) although a surge in domestic production was seen following the introduction of favourable financial incentives.

Renewable electricity can also be obtained from wave and tidal power, and this marine energy has been identified as important emerging technology (HMG, 2009b). It was predicted that the sector could be worth between £900 million and £4.2 billion annually to the UK economy by 2050 (Renewable UK, 2010; Carbon Trust, 2006b), although more recent estimates have suggested that the value of this market to the UK could be as high as £29 billion per year at its peak (Carbon Trust, 2011). The UK currently leads the global effort to exploit wave and tidal resources, with 40 marine energy devices in development, compared to 23 in the United States, 11 in Canada, and less than 10 in the other countries for which information was available (Khan and Bhuyan, 2009). This places the UK in a strong position to dominate the marine renewable energy market, its share of which could be as high 20% of the sector's global value (Carbon Trust, 2003).

Electricity generation from marine energy is, therefore, an integral component of the UK's energy strategy. The UK Government's commitment to the marine renewable sector is demonstrated by its allocation of more than £77 million to accelerate the development and deployment of wave and tidal power systems, which includes substantial investment in academic research (HMG, 2009b; SWRDA, 2010). The Government's Low Carbon Industrial Strategy also designated geographical Low Carbon Economic Areas within which efforts in research, development, demonstration and manufacture of particular non fossil fuel technologies will be concentrated (HMG, 2009b). In January 2012, the South West Marine Energy Park (extending from Bristol to Cornwall) was the first such collaborative partnership for wave and tidal energy expertise. It was estimated that the value of goods and services generated by the marine energy sector in the South West represented a Gross Value Added of £4.9 million in 2005 (RegenSW, 2005). The economic development of the sector is implied by 2007/08 data, which suggested that the wave and tidal power market across the UK was worth £73 million (Innovas, 2009).

Marine Energy

The total global resource of marine energy could exceed 92,000TWh per year (AEA, 2006) and is equivalent to more than six times the total electricity currently consumed worldwide (IEA, 2009). However, much of this marine energy resource is far from population centres or is otherwise technologically inaccessible. Thus, a more realistic estimate for the contribution of this sector is 10-25% of global electricity supply (Dal Ferro, 2006). There are different ways to extract energy from the sea, including the use of temperature and salinity gradients, although over 95% of marine energy projects in development concern the exploitation of wave and tidal resources (AEA 2006).

A variety of surface and sea-bed devices can collect the energy within waves for electricity generation. Common types include absorber systems, in which energy is generated as the waves move a floating buoy relative to a fixed reference, and Oscillating Water Column devices, which use the passage of waves to compress and expand an air column and drive a turbine (Khan and Bhuyan 2009). The amount of energy that can be extracted from waves depends on their height and the time interval between the passage of successive peaks (Carbon Trust, 2006a).

There are two possible ways to use the energy within the tides. Where there is a sufficiently large tidal range, barrages can be constructed to hold back the ebbing or flooding tide to create a difference in water level on either side of the dam. The gravitational potential energy within this height difference is used to drive turbines (SDC, 2007).

Alternatively, the current flow caused by tidal movement (the tidal stream) can be harnessed in a similar way to wind power extraction. Constrained channels, often found near headlands, between islands or between islands and the mainland, accelerate the water flow, and so are particularly important sites for tidal stream energy (AEA, 2006). The kinetic energy in tidal currents is proportional to the cube of the velocity, so a relatively small change in current speed equates to a much larger proportional increase in power output (SDC, 2007).

1.4 The Wave and Tidal Power Sector in the UK

The power supplied by wave and tidal technologies is potentially very significant for future UK energy supplies. Estimates suggest that the UK has 35% of Europe's attainable wave resource, and 50% of its tidal stream resource (Carbon Trust, 2006a). Accessing this could supply 20% of the UK's electricity demand, with 50TWh per year supplied by wave power and 17TWh per year from tidal stream energy (Carbon Trust, 2006a; SDC, 2007). This is enough electricity for 21 million UK households (HMG, 2010). Deployment of wave and tidal power could, by 2050, have mitigated at least 70 million tonnes of carbon dioxide emissions, worth nearly £1.5 billion (HMG, 2010). This would represent 26% of the carbon emissions reduction required during the period 2020-2050.

The deployment of tidal stream devices becomes viable where current speeds exceed about 1.2ms^{-1} (van Haren, 2010), but most sites currently under development have current velocities closer to 2.5ms^{-1} (Figure 1, Table 1). Barrage schemes to exploit tidal range energy are similarly restricted, to hypertidal estuaries and embayments with a mean tidal range greater than 6m (Kirby and Retière, 2009), although the continuing of low head turbines could allow tidal range energy to be exploited at locations with a lower mean range.

At the end of January 2010, the installed capacity of the wave and tidal sector in the UK was 2.4MW, planning consent had already been obtained for an additional 27MW, and a further 52.5MW of small scale projects were in development (RenewableUK, 2010a). In March 2010, the Crown Estate announced the results of the first commercial tenders for wave and tidal stream farms, awarding leases for 1,200MW to be installed in the Pentland Firth by 2020 (Crown Estate, 2010a).

HMG (2010) reports that 1-2GW of installed wave and tidal power capacity (or 3% of the UK's renewable electricity supply) is possible by 2020, which would be the largest contribution by deployed marine renewables in Europe (RenewableUK, 2010a). As the wave and tidal sector currently lags some 20 years behind wind power, this projection is in line with the trajectory on which wind energy developed (Mueller and Jeffrey, 2008).

As yet, no tidal barrages have been commissioned in the UK. A feasibility study for a scheme in the Mersey estuary had a defined timetable to permit generation by 2020, subject to obtaining the required consents (Scott Wilson, 2010), but the project stalled in 2011 due to the projected cost (Mersey Tidal Power, 2011). Another recent feasibility study concluded in 2010 that there was no convincing case for a barrage in the Severn in the immediate term due primarily to the high capital cost and the long construction time, which would prevent the scheme making any contribution to 2020 emissions reduction targets (DECC, 2010b). The study concluded that the situation may be reviewed as early as 2015, in the light of 2050 emission reduction targets (DECC, 2010b), but almost immediately private developers began to seek support for proposals for a large barrage across the Severn. Following an inquiry, the House of Commons Energy and Climate Change Committee report (2013a) again concluded that the case for such a barrage was unproven, and alternative tidal range technologies may have greater potential. An alternative scheme set out by RegenSW to harness the energy of the Bristol Channel using a range of tidal technologies and techniques has been highlighted by the Government as a useful framework for moving the debate forward (House of Commons Energy and Climate Change Committee, 2013b).

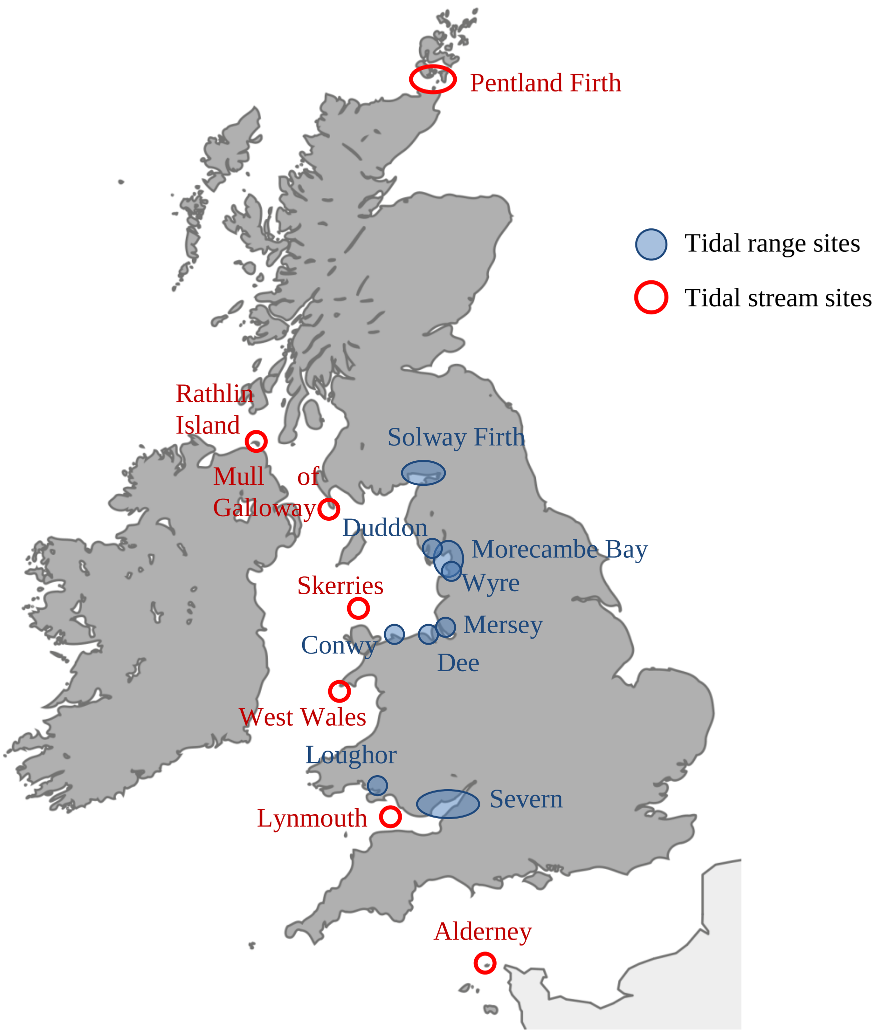

Figure 1. The main sites with significant tidal energy resources around the UK

Table 1. Sites around the UK with the most significant potential tidal energy resources

Tidal Range			**Tidal Stream**		
Site	**Power output (TWh/yr)**	**Reference**	**Site**	**Power output (TWh/yr)**	**Reference**
Severn	11.7 – 20.0	SDC, 2007; World Energy Council, 2007; Burrows et al, 2009a	Pentland Firth	12.7	SDC, 2007
Solway Firth	6.8 – 10.8	World Energy Council, 2007; Burrows et al, 2009a	Alderney	3.1	SDC, 2007
Morecambe Bay	3.3 – 7.1	Burrows et al, 2009a	Rathlin Island	0.9	SDC, 2007
Dee	0.8 – 1.4	Burrows et al, 2009a	Mull of Galloway	0.8	SDC, 2007
Mersey	0.6 – 1.0	SDC, 2007	Lynmouth	0.5	Walkington and Burrows, 2010
Duddon	0.2	SDC, 2007	Skerries	0.4	Walkington and Burrows, 2010
Loughor	0.1-0.2	SDC, 2007	West Wales	0.4	Walkington and Burrows, 2010
Wyre	0.1	SDC, 2007	Mersey	0.1	Walkington and Burrows, 2010
Conwy	0.1	SDC, 2007			

1.5 Research Motivation

The use of marine energy is intended to mitigate climate change, but its deployment is not without welfare costs. As will be discussed in more detail in the following chapter, tidal barrages could have very significant negative effects on the environment by modifying water circulation, sediment behaviour, water quality and habitats, restricting the passage of migratory fish, posing a collision risk to fish and marine mammals, and changing land and amenity uses. Environmental Impact Assessments are widely used to evaluate the potential effects of developments in ecological terms, and Strategic Environmental Assessments also consider the impacts on aspects of human welfare. What is not incorporated into standard environmental assessments are tools to effectively quantify the disparate costs and benefits in a way that provides transparency when trade-offs are considered during the policy-making process. Existing scoping studies and impact assessments for tidal power make no attempt to evaluate whether the benefit of carbon emission reductions outweighs the costs of loss of habitat, or to evaluate trade-offs between the additional costs of technological alternatives that mitigate barrage impacts and the benefits obtained by reducing environmental damage.

Economic valuation of natural resources provides a common metric for these comparisons. It allows for non-market-based values of ecosystems to be quantified in terms that permit their direct comparison with the exploitation of manmade capital (Costanza et al., 1997; Barbier, 2007). These non-market values include climate regulation, bioremediation of waste, nutrient cycling, and the provision of dampening services and flood control that reduce the impact of natural hazards. Marine ecosystems also have value in fulfilling cultural and emotional needs. The indirect nature of the benefits derived from these, and similar, ecosystem functions mean they have, historically, been undervalued (de Groot et al., 2002). The growing acceptance of ecosystem valuation and its important role in informing management strategies was highlighted by the Millennium Ecosystem Assessment (2005), TEEB (2010) and the UK National Ecosystem Assessment (2011).

1.6 Research Aim and Objectives

Renewable energy can provide significant benefits by reducing greenhouse gas emissions and increasing energy security, which accrue at national and global scales. However, there are also costs associated with tidal power development, and these are local. The study will consider how to value these local-scale environmental changes, such that they can be better assessed and compared to the national and global scale benefits of tidal range energy generation.

This sector has been selected because tidal power plants have yet to be deployed on a large scale, and so there is greater scope to evaluate how economic valuation could be employed at early stages of the planning and consent process. Also, tidal barrages have the potential to affect a wider range of environmental goods and services than tidal current, wave energy or offshore wind developments. In particular, they impact upon intertidal mudflats, and little is known about the preferences of the general public for these habitats.

In the above context, the aim of this research is to investigate values attached to changes in the provision of estuarine mudflats resulting from the development of a tidal barrage. Thus, the results can be used to inform policy for this technology while providing a frame for understanding the formation of public preferences over marine ecosystems. Within this broad aim, the objectives of the study, and specific research questions it seeks to address, are:

Objective 1: To investigate the application of an ecosystem services approach to complement environmental impact assessment and support local-scale planning decisions.

- How can an ecosystem services approach be applied in practice to the assessment of the multiple positive and negative impacts that could be expected from a tidal range energy development?

Objective 2: To determine a monetary value for welfare changes associated with changes in mudflat provision using appropriate techniques, particularly stated preference to allow the elicitation of non-use components.

Objective 3: To assess the validity and reliability of the value elicited.

- Do the values elicited demonstrate validity in general economic theory in particular with regard to level of provision of the good and distance from the affected site?
- Is validity also demonstrated as regards the influence of personal characteristics (such as respondent income, level of knowledge, use, and pro-environmental attitude)?
- Is the elicited willingness to pay reliable, as demonstrated by consistency across different methods?

Objective 4: To consider the policy implications of the research.

- How does WTP to reduce mudflat loss compare to the value of carbon savings in different tidal range energy scenarios?
- How can the outcome of the research best inform policy recommendations?

The key focus of the work is to support marine planning through improved understanding of how best to maximise benefits and minimise costs as the development of the marine energy sector increases. As the application of valuation techniques to marine ecosystem benefits has been relatively limited, this research will also contribute to the development of frameworks and methods which have wider practical application in this context. This study will contribute to knowledge by applying recognised methods in a new situation, but its purpose is not to extend the underlying theory or to improve econometric models. However, the study will examine how multicriteria techniques (in this case the Analytic Hierarchy Process) can complement stated preference assessments by generating a measure of pro-environmental attitude that relates specifically to the good in question.

1.7 Thesis Outline

In the following chapter, tidal energy generation is explored in more detail, and the environmental, social and economic costs and benefits of tidal barrages are discussed. Chapter 3 reviews the concept of the ecosystem services approach and its application to the assessment of local-level environmental impacts. A methodology for classifying the benefits provided by a macrotidal estuary and evaluating the environmental changes that could result from barrage construction is also be proposed, and tested in the case study site of the Taw Torridge estuary in North Devon.

Chapter 4 provides an overview of issues in environmental valuation and the methods by which it can be achieved, with a particular focus on stated preference techniques, as these are only means by which non-use values can be determined. Chapter 5 details the development of the contingent scenarios, describing plausible barrage options and discussing the outcomes of focus groups. The design and implementation of survey instruments using i) contingent valuation supported by the multi-criteria Analytic Hierarchy Process and ii) a choice experiment are described in Chapter 6. The concluding chapters present and discuss the results of the empirical work.

2 The Costs and Benefits of Tidal Range Energy Generation

2.1 Introduction

This chapter reviews in more detail the environmental, social and economic issues of developing tidal barrages in the UK. The advantages of barrages over other renewable energy schemes including tidal current turbines are presented, and the financial and external costs of energy from tidal barrages are discussed. The potential environmental and social impacts of barrages (both positive and negative) are explained in detail. Options to mitigate the negative impacts through altered operating modes or the use of alternative tidal range energy schemes such as lagoons and tidal fences are also considered. This review highlights the need for methods that can quantify the large range of potential impacts and provide transparency when assessing trade-offs between 'traditional' barrages and alternative schemes.

2.2 Advantages of Tidal Power

In addition to the pros and cons shared with other forms of renewable compared to fossil fuel sources of electricity, tidal energy exploitation has particular advantages over wind and wave power, particularly in overcoming intermittency issues.

Increasing the security of energy supply requires that a diverse range of sources is utilised in the generating mix (Rourke et al., 2010b). However, renewable energy sources are often intermittent and unpredictable and therefore require reserve generating capacity to fill production gaps (Hardisty, 2008). This is particularly true for wind power, which only makes a low contribution to energy security because of the significant back-up requirements.

Relying too heavily on wind power may lead to a large variation in energy output, as weather conditions are often homogenous over large areas of the UK. The inclusion of wave and tidal power significantly reduces the risk of extended periods during which the energy output of renewables is low, to the extent that using mix of 60% wind energy to 40% marine could save £901 million, or 3.3% of the annual wholesale cost of electricity (Redpoint, 2009). Tidal power is particularly important to this, as it is generated entirely independently of weather systems, while wave power is affected by wind conditions, particularly at a seasonal level. In addition, the tides are regular and entirely predictable, which allows for better grid planning than is possible for wind or wave power (HMG, 2010).

The movement of the tides is nonetheless intermittent, and the power output of tidal schemes will vary both in size and with time. Marine current turbines will generate the largest amounts of power about every six hours at mid-tides when the current flow is strongest, but this will reduce to almost nothing at slack water as the tide turns (Hardisty, 2008). Barrages are also only operational for part of the day, as there is a holding period while sufficient head develops (Burrows et al., 2009b). There is further variation in potential power output over the course of a spring-neap cycle, as the tidal amplitude on springs can be twice that of neap tides (Prandle, 2009). The power output of a barrage on the smallest neap tides will be only 25% of the peak spring capacity, while the lowest neap flow through a tidal current turbine will generate less than 10% of the maximum power capacity (Metoc, 2007). The time of high water is approximately one hour later every day, and so the timing of peak energy will also vary each day throughout the spring-neap cycle.

There are two possible ways that the design of a tidal barrage can reduce some of the problems associated with tidal variability. One of these is to construct a second basin within the barrage, into which water can be pumped using some of the power produced during ebb generation. This arrangement allows a degree of energy storage and provides greater flexibility in the timing of generating periods (Frau, 1993; Rourke et al., 2010b). An alternative is to operate the barrage in two-way mode, and generate power on both the flood and the ebb tide. Barrages that employ ebb generation only will begin to produce power about three hours after high water, and will continue to generate electricity for about four hours on each tidal cycle (eight hours over the full day) (Metoc, 2007). In two-way mode, this generating period can be extended to more than seven hours during a mean spring tidal cycle (Xia et al 2010).

The issue of intermittency can also be mitigated through the use of multiple tidal power installations strategically placed around the coast. At any particular location, every high spring tide (and related maximum energy output) will occur at the same time of day, but this time of peak energy is not the same for all locations around the UK coast. The tide progresses from the Celtic Sea around into the North Sea, and so the time of high water becomes progressively later moving up the west coast (Hardisty 2008). There is a delay of approximately five hours between the time of high water in the Severn and in the estuaries of the Dee, Mersey, Solway Firth and Morecambe Bay. Modelling suggests that tidal barrages operating in ebb mode in these locations would be out of phase, and could provide up to 20 hours of electricity generation every day (Figure 2), with two equal power peaks as the output from the Severn would be roughly equal to that of the other estuaries combined (Burrows et al., 2009b).

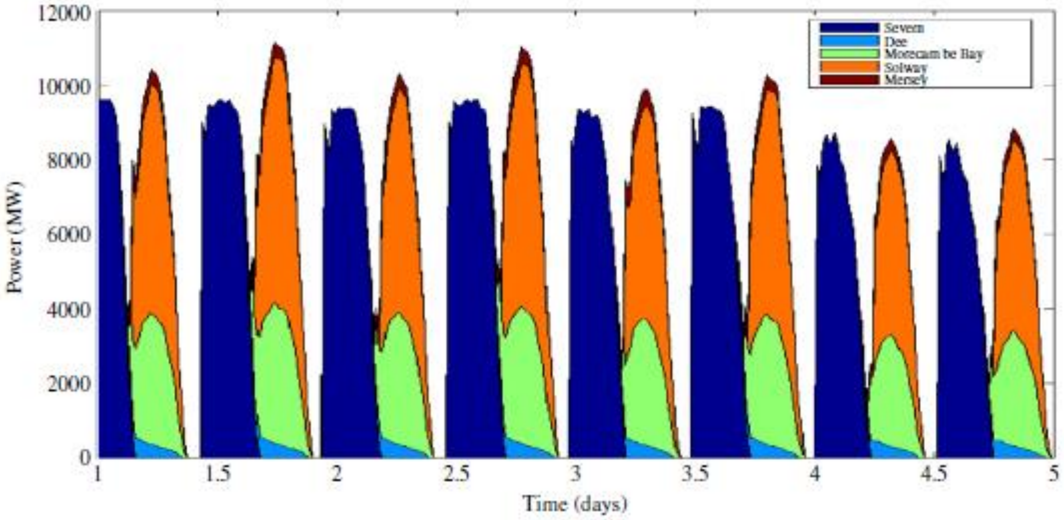

Figure 2. The potential timing and magnitude of power produced by tidal barrages in five estuaries on the west coast of England over a five day period on spring tides (Burrows et al. 2009b).

Electricity from carefully sited tidal stream farms could similarly allow a near-continuous base load supply (Clarke et al., 2006). There is a phase delay of about two hours between the peak tidal currents of the Severn, Menai Strait, Mersey, Clyde, Tyne, and Humber. A model suggests that 600 tidal current devices spread across these sites would generate an almost constant 45MW throughout the tidal cycle (Figure 3) (Hardisty, 2008). It is also possible to store energy, and technological advances in this area are ongoing. The cyclic and predictable nature of tidal power makes it particularly compatible with energy storage options which include flywheels, batteries, pumped hydroelectric power, compressed air storage, superconducting magnetic energy storage and capacitive energy storage (Bryden and Macfarlane, 2000; Leijon et al., 2003).

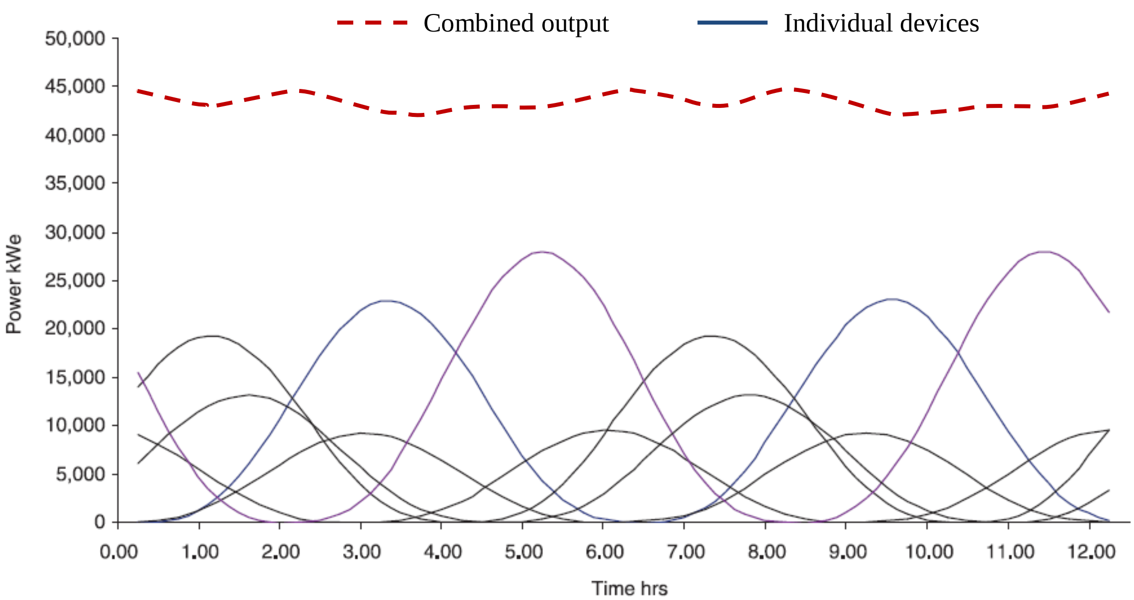

Figure 3. The combined and individual power output during a tidal cycle from tidal current arrays located around the west and east coasts of the UK (Hardisty, 2008)

Tidal Barrages

Tidal barrages have specific advantages over tidal current devices. The large quantity of electricity that could be generated by barrages makes them particularly attractive renewable energy options. A Severn barrage alone could provide 5% of the UK's electricity requirements (RegenSW, 2008), and the combined output of tidal barrages in four estuaries in northwest England could meet approximately half of the present energy needs of that entire region (Burrows et al., 2009b). The longevity of tidal barrages is also a considerable advantage. A tidal barrage could last 120 years, compared to 40 years for a nuclear power plant and just 20 years for a wind farm (SDC, 2007).

Also, using the energy of the tidal range to produce electricity has already been proven effective, as evidenced by the La Rance barrage, which has been in operation since 1966 (Frau, 1993). The tidal stream and wave sectors however, remain at an early stage of device development. The only installation of multiple, full-scale devices is the Agucadoura wave farm in Portugal (IMechE, 2008). Understanding of the environmental impacts of marine energy devices is limited as few have been deployed anywhere in the world. This is particularly true for wave and tidal current devices, as there is little more than 10 device-years of operational experience at sea (Mueller and Wallace, 2008). The limited number of full-scale demonstration devices, and the complete absence of pre-commercial tidal stream farms, also means that it is difficult to develop tools to predict performance, there are no industry standards, and the large-scale implications of the technology itself are still unproven (AEA, 2006).

2.3 Economic Issues for Tidal Power

Predicted price of energy from tidal power

Tidal barrages are relatively expensive to construct and operate, and the comparatively low price of fossil fuels has been a major factor in the reticence to commission tidal power plants, despite repeated feasibility studies (Burrows and Ertekin, 2009). There is little opportunity for costs to reduce as deployment increases because tidal barrages are suitable for only a few sites and employ mature technology for which the systems and supply chain are well established (HMG, 2010).

Modelling studies indicate that the economics of a tidal barrage can be affected by a number of factors within the design (Burrows et al., 2009a). Barrages operating in ebb-generation mode can increase the total energy output and reduce the price of the electricity generated if they use pumping to further increase the difference in head before starting the generating phase. Other possible impacts of design changes depend on the circumstances of individual barrages. Operating in two-way rather than ebb-generation mode could result in: less energy at a higher unit price for a barrage in the Solway Firth; in more, but still more expensive, energy for a scheme in the Mersey; and in more energy that is cheaper for a Morecambe Bay barrage (Burrows et al., 2009a). One consistent factor appears to be that for a given location, two-way generation becomes more economically viable as the number of turbines used increases.

Barrages are major infrastructure projects, which take a long time to build and bring a significant risk of cost overruns (SDC, 2007). Estimates for the cost to build a Severn tidal project range from £2 billion to £4 billion for the smaller barrages and lagoons, to £18 billion for the Cardiff-Weston barrage (Parsons Brinckerhoff, 2008a; Black and Veatch, 2007). The unit cost of electricity that would be generated is, at 6-10p/kWh, lowest for the Shoots barrage (near the Severn road crossings), rising to 11-13p/kWh for the Cardiff-Weston barrage (Parsons Brinckerhoff, 2008a; Frontier Economics, 2008). These costs place the Shoots barrage about on par with nuclear generation, and not significantly higher than the cost of energy from on- or off-shore wind, while output from the Cardiff-Weston barrage would be cheaper only than that from fuel cells and solar photovoltaics (Frontier Economics, 2008). Other modelling shows that the unit cost of electricity would be of a similar order of magnitude for barrages in northwestern England (Burrows et al., 2009a), although some proposed options for the Solway Firth could lead to an electricity unit cost of more than three times that of the Cardiff-Weston barrage (Halcrow Group et al., 2009).

Temporal distribution of costs and benefits

The long lifespan of tidal barrages means that these projects have temporal inequalities, with the capital costs occurring immediately, but the production benefits continuing for later generations. Consequently, the discounting of cash flows is critical to the effective comparison of energy options. The high capital cost and long lifespan of tidal barrages put them at a disadvantage under typical net present value calculations. Unless a very low discount rate is used, only the first 40 years of revenue will tend to be material in the calculation, ignoring any income from the remaining 60-80 years of operation (Parsons Brinckerhoff, 2008a). A discount rate of up to 15% has been suggested for private-sector barrage projects, and this weighting would result in a unit cost of electricity from a Cardiff-Weston barrage of 27.0p/kWh (Parsons Brinckerhoff, 2008a). The Treasury’s preferred discount rate of 3.5% (possible because of the lower risks in State sector projects) would result in a unit cost of 6.5p/kWh (Parsons Brinckerhoff, 2008a). Examples from hydroelectric projects (with similar capital costs and long life) have shown that the high discount rates applied by private developers do not reflect the actual situation, in which hydroelectric power becomes economically attractive just a few years after construction (Baker, 1991). The UK Government therefore advocates the adoption of a Declining Discount Rate for projects with impacts more than 30 years in the future (HMT, 2003).

Additional Costs

Unit prices of energy are based on a narrow definition of costs and benefits that just takes account of the financial implications of production and distribution (Hohmeyer, 1992). These are private costs, incurred by the generators and suppliers and paid for by the individuals, households, companies or other organisations which consume the energy (Verbruggen et al., 2010). Comparison of the prices of energy from different sources assumes that all other factors in generating the energy are equal (Allan et al., 2008). There are different social and environmental costs associated with different forms of energy. These external costs do not factor in the unit price, and are paid for by third parties who are not involved in the supply or consumption of the energy (Hohmeyer, 1992). As yet, there is no universally accepted method to comprehensively quantify the full price paid by society for these external costs (Rourke et al., 2010a; Verbruggen et al., 2010), and it remains the energy prices, not the wider external costs, that are the principal driver in people's decisions about energy (Verbruggen et al., 2010).

The intermittency of tidal energy brings a significant cost to the wider economy, because reserve capacity or storage must be utilised to fill generating gaps, and this has financial implications (Bryden and Macfarlane, 2000). The costs of any reserve capacity may come at a premium because providing the flexibility to 'ramp-up' supply means that the plant providing the reserve will be running at only partial load for most of its generating cycle, and therefore at a loss (Redpoint, 2009). Continual variation in output also subjects the back-up generators to increased wear and tear, which shortens their lifespan (Denny, 2009). As the reserve is likely to be generated by conventional plant, it also brings with it all the external costs of fossil fuel or nuclear generation. These may be particularly high for reserve generation capacity, as marginal plant tends to be less efficient and produces more carbon (Redpoint, 2009).

A further cost of tidal power can arise from the mechanisms put in place by the Government to support the tidal energy industry. Modelling of subsidy schemes suggests that consumers lose under schemes like the Renewables Obligation, as statutory renewables quotas cause an overall increase in the price of electricity (Palmer and Burtraw, 2005). The impact on consumers of any potential higher Renewables Obligation banding for tidal power will form part of the Government's deliberations on the issue (HMG, 2010).

On the positive side, the utilisation of tidal energy contributes to increased security of supply. Local control over energy resources isolates the supply system from external fluctuations in the quantity and price of energy supplied, which can bring significant benefits (Allan et al., 2008). At the extreme, increased security of supply also brings the benefit of the reduced risk of war over diminishing fossil fuel resources (Hohmayer, 1992). This is not an entirely unrealistic scenario, given the recent diplomatic incident between the UK and Argentina over the exploitation of oil reserves off the coast of the Falkland islands (BBC, 2010).

As an alternative generating source, tidal power also provides a capacity benefit, which equates to the saved cost of building and operating conventional power plants to supply the same quantity of electricity (Denny and O'Malley, 2007). Even barrages, with their high capital cost, can bring this benefit. For example, the power produced by a Cardiff-Weston barrage would equate to the combined output of two typical nuclear power stations (such as Sizewell B and Hinkley Point B (DECC, 2010c), and would have a lifespan three times greater (SDC, 2007). With the cost of building a new nuclear power estimated at about £2 billion (HMG 2008), and with the additional nuclear fuel and waste disposal costs over the 120-year lifetime of a barrage, tidal range power becomes much more competitive for the long term. The issues of intermittency (as discussed above) must, however, be taken account of in capacity benefit calculations.

If the UK maintains its leading position in the sector, then tidal energy could also bring the wider economic development benefits associated with securing a significant share of global export market, as Denmark has done with wind power and Japan with solar photovoltaics (RenewableUK, 2010b). Estimates of the possible value of the sector vary considerably, but by 2050 revenues from the marine energy sector could be at least £600 million annually and perhaps even exceed £4 billion each year (Carbon Trust, 2006b). This economic benefit of exporting knowledge and technology would be spread throughout the supply chain, and could include the creation of up to 16,000 jobs (HMG, 2010).

External Costs and Benefits

A further significant benefit of tidal power plants is that of greenhouse gas reduction, as they produce no emissions during electricity generation. Even accounting for the emissions resulting from the materials, construction, and decommissioning, the carbon dioxide produced by a Severn barrage would still be one to two orders of magnitude lower than for a Combined Cycle Gas Turbine, and have been estimated at $2.4gCO_2/kWh$ and $1.6gCO_2/kWh$ for the Cardiff-Weston and Shoots barrage options respectively (Black and Veatch, 2007). The carbon payback period would be between five and eleven months, depending on the location and the type of fossil fuel replaced.

There is a price available for this carbon saving, which is determined by the European Union Emissions Trading Scheme (ETS), a cap-and-trade system for large industrial sectors (HMG, 2009b). This is an opportunity cost that does not take account of the social costs, and also does not price the other emissions from fossil fuel combustion which include sulphur dioxide and nitrous oxide (Denny 2009).

The social costs of carbon are primarily those associated with climate change. These are global issues and therefore enormous in scale, and include risks to food production from altered weather patterns, as well as coastal flooding and contamination of freshwater supplies caused by sea level rise (UNEP, 2010). Changes in the timing of the seasons and in species abundance and geographical ranges have been observed, while species such as coral reefs that cannot adapt to a warming environment are increasingly at risk (IPCC, 2007). Climate change is also likely to adversely affect public health, as more frequent heatwaves, floods and droughts, more widespread malnutrition, and increasing incidents of malaria, dengue and other diseases all take their toll (Haines et al., 2006).

Replacing fossil fuel sources with renewable energy also reduces the costs related to the direct pollution effects that emissions have on human health, agriculture and the environment, which include respiratory diseases and acid rain (Hohmayer, 1992; Mirasgedis et al., 2000; Mukhopadhyay and Forssell 2005). There have also been repeated catastrophic accidents associated with the extraction and delivery of, and power generation by, fossil fuel and nuclear energy sources, which range from mining and refinery accidents to oil tanker spills and the Chernobyl and Fukushima disasters. Society has incurred significant costs from these incidents, and there are no such risks with tidal energy. Taking account of the external costs of conventional energy generation suggests that it is actually expensive for society, while more widespread use of renewable energy lowers the societal cost (Hohmayer, 1992; Mirasgedis et al., 2000).

2.4 The Potential Marine Environmental Impacts of Tidal Barrage Construction

There are specific external costs associated with the environmental impacts of tidal power developments, and the negative effects of tidal barrage construction may be particularly significant.

Ecological Impacts

Construction and presence of a physical structure

a) Benthic Communities

The construction of foundations for tidal power plants will disturb seabed sediments, as will laying cables to connect the installations to the shore. The plumes of sediment created during these processes may have detrimental consequences for benthic marine life, through direct smothering as the material is deposited (Gill, 2005) or by interference with feeding or digestion while high concentrations of material remain in suspension (Bock and Miller, 1994). The degree of the impact will depend on the quantity of material, as well as on the existing seabed type and communities present (Harvey et al., 1998). The instantaneous deposition of large quantities of sediment, such as during the disposal of dredged material, can result in total mortality (Miller et al., 2002), while burial beneath thinner layers up to 25mm thick may have no discernible effect (Trannum et al., 2010). If the deposited material is not identical to the sediments on which it settles, or has been contaminated, the rate of mortality may increase (Trannum et al., 2010; Holdway, 2002).

The community that immediately recolonises the area is likely to differ from that which existed prior to construction. Opportunistic species will tend to dominate, and introduced and invasive species may rapidly exploit the site (Bulleri and Chapman, 2009). It may take more than two years for the community to return to a closer resemblance of its original state (Harvey et al., 1998).

Habitat will be lost beneath the footprint of the power plant, but the surface of the new structure will provide new areas for colonisation. The presence of any hard substrate in areas of soft sediment (such as a muddy estuary) will act as a settlement surface, attracting species not otherwise able to colonise the area and increasing biodiversity. Evidence suggests, however, that the assemblages of species colonising artificial structures differ from those on natural reefs (Moschella et al., 2005). The principal reasons for the differences are that artificial constructions have little similarity to natural habitats. Walls and pilings tend to be vertical, homogenous structures, which are made of unnatural substances, and lack microhabitats and areas of refuge (Bulleri and Chapman, 2009). They also create shelter and cause shading of the sea floor, extending the footprint of the impact.

b) Passage of Mobile and Migratory Species

Tidal barrages that obstruct the entire width of an estuary would inhibit the movement of marine species. Barriers that prevent anadromous fish such as lamprey and shad from reaching their freshwater breeding grounds are a known factor in the decline and extinction of these species (Larinier, 2001). Dams and similar obstructions also have implications for marine fish and crustaceans which, while not migratory, nonetheless undertake significant movement up- and downstream as part of their normal seasonal activity as they transit between breeding, nursery and feeding grounds (Henderson and Bird, 2010).

Experience with hydroelectric power plants illustrates that it is possible for fish to pass through the turbines and sluices contained within a barrage. However, turbine passage brings significant risk of injury or mortality from sheer stress, pressure changes, cavitation and collision (Turnpenny et al., 2000). Fish also appear to be at greater risk of predation in the proximity of a dam, which may be a result of the concentrating effect of the structure, or of fish becoming stressed or disorientated following turbine passage (Larinier, 2001).

Noise

Noise causes disturbance, stress and potentially physical injury. The high noise levels during construction are of particular concern, especially for tidal barrage schemes, with their prolonged construction period (Parsons Brinckerhoff, 2008b). Noise may affect many different marine animals, including seabirds and fish (Parsons Brinckerhoff, 2008b; RGU, 2002; Kikuchi, 2010). Sound also plays an important role as an orientation cue for the pelagic larvae of invertebrates, whose ability to detect suitable settlement sites may be affected by anthropogenic noise (Montgomery et al., 2006; Kingsford et al., 2002).

Noise will also be generated during the operation of tidal power plants, although the potential effects are not well understood. It is known that marine mammals can detect the noise created by operating wind farm (Koschinski et al., 2003), although the low levels are unlikely to result in physical damage to the animals (Madsen et al., 2006). As the turbines are located below the surface, tidal energy is likely to create more underwater noise that wind farms during operation. Maintenance will also result in intermittent periods of higher noise levels (Parsons Brinckerhoff, 2008b).

Changes in Water Level

Tidal barrages have a significant effect on sea levels within the impounded basin, usually reducing the tidal range by about half (Frau, 1993). Where ebb generation is used, the tide will not recede to as low a level at low water as previously, while flood-generation mode will result in a lowered high water level (Figure 4). Two-way generation reduces both low and high water levels, but to a much lesser extent (Burrows et al., 2009b).

The effects on water level can be significant. An ebb-generation barrage in the Severn, for example, could reduce the spring tidal range from 12.3m to 4.5m, and increase the mean sea level in the basin by 3m (ABPMer and HR Wallingford, 2008). A modelled scenario suggests that a barrage across the mouth of the Mersey estuary would, similarly, reduce the tidal range by up to 60% and increase the upstream low water level by 4m (Burrows et al., 2009a). The effect of holding back the tide prior to ebb generation also results in an increased period of high water, which continues for several hours (Frau, 1993), and which may raise the level of the water table (Burton et al., 2010).

The effects on sea level extend to the open sea. The tidal range could be reduced by 10% in the area immediately downstream of a Severn barrage (Frau, 1993), and the barrage could continue to influence the tidal range as far as 100km seaward (ABPMer and HR Wallingford, 2008). Smaller estuaries are too short for resonance effects, so the far-field implications will be reduced (Prandle, 2009). Conversely, were tidal barrages to be deployed in multiple locations, modelling suggests that the effects on sea level could become more widespread. The construction of barrages in the Severn, Dee, Mersey, Morecambe Bay and the Solway Firth would reduce the tidal amplitude at the barrage locations, but could potentially increase the tidal level on the coast of Ireland by up to 20cm (Burrows et al., 2009a).

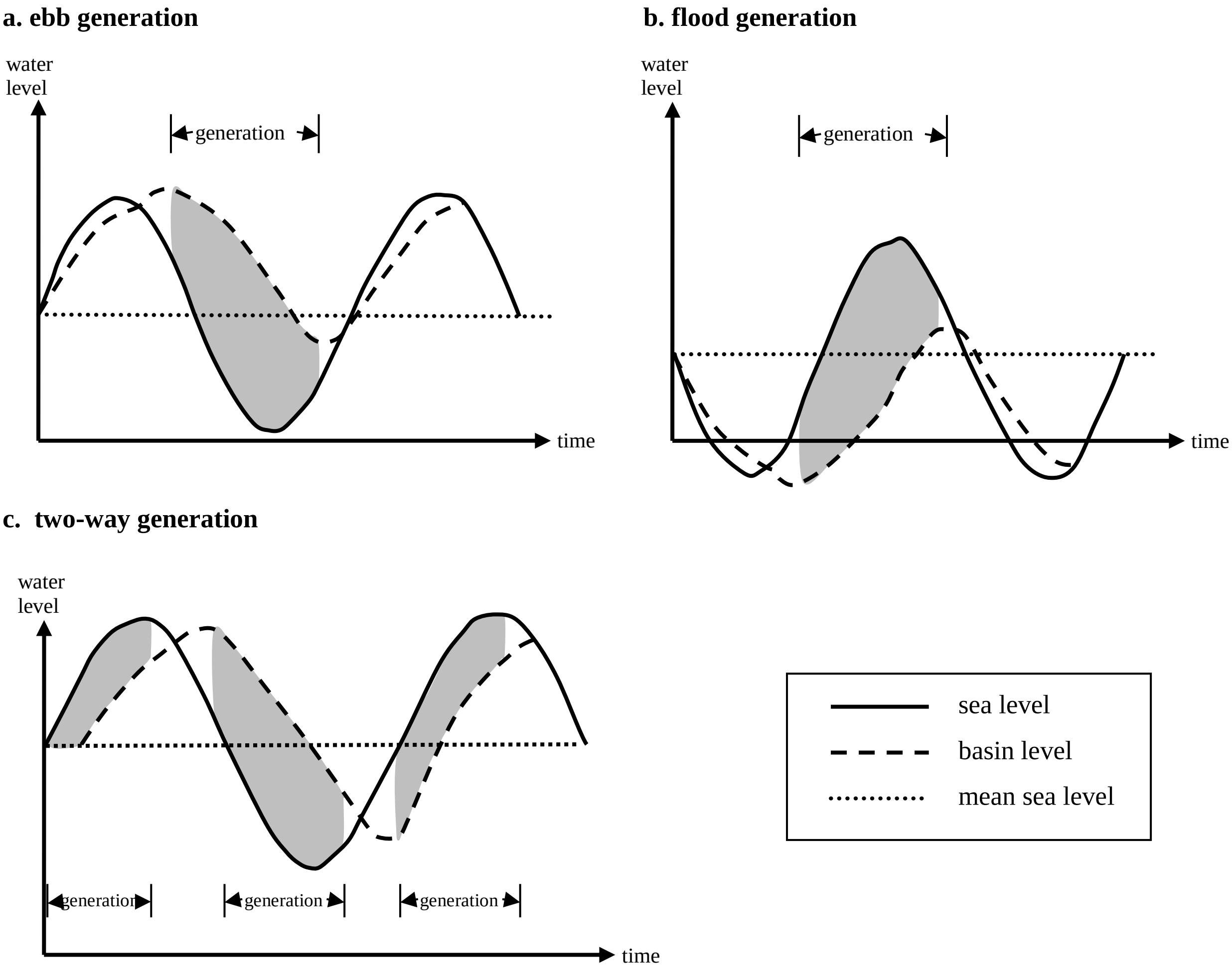

Figure 4. The generating periods (shaded grey) and relative water levels within and outside the basin for different tidal barrage operating modes (adapted from Burrows et al., 2009b)

Uplifting the level of low water within a tidal barrage basin will permanently submerge a considerable area of what was previously intertidal habitat. A Severn barrage could reduce the upstream intertidal area by 76%, which, in the case of the Cardiff-Weston option would result in the loss of 14,428ha intertidal habitat (Black and Veatch, 2007). Other estimates place the loss of intertidal area at 20,000ha (ABPMer and HR Wallingford, 2008).

The intertidal area is not a homogenous feature, and the exact ecological implications of any loss of habitat will depend on the specific biota found in the affected location. The intertidal areas of the Severn and other hypertidal estuaries on the west coast of Britain contain large expanses of mudflat and saltmarshes. Environmental scoping studies and impact assessments for tidal barrage developments focus particularly on the implications that the loss of mudflats and saltmarshes would have for wading birds and waterfowl (Parsons Brinckerhoff, 2008c; Halcrow Group et al., 2009; Scott Wilson and EDF, 2010). This reflects the emphasis of statutory instruments on the protection of the migratory bird populations supported by UK estuaries (JNCC, 2010).

The survival of bird populations depends on the abundance of, and energy available from, prey, the size of the feeding area and the time available for feeding (Goss-Custard et al, 2006). The availability of breeding and nesting grounds is similarly crucial, and species such as the Redshank (*Tringa totanus)* are particularly vulnerable, as about half of Britain's breeding population of the species nests in saltmarshes (Norris et al., 1998). The loss of feeding and breeding grounds resulting from the changes in sea level associated with a tidal barrage would be very detrimental to the affected birds, as evidenced by schemes such as the Cardiff docklands redevelopment which inundated 200ha of mudflats in Cardiff Bay to form a freshwater lake (Burton et al., 2006). Many waders are faithful to a particular site and so may not find new wintering areas. Even those that do are unlikely to thrive in the new environment as they are at a competitive disadvantage compared to the resident birds (Burton et al., 2010). As habitat is lost, the increased competition at remaining sites increases the mortality rate within the wider population of the affected species (Goss-Custard et al., 2002).

Waders and waterfowl are just one group of marine species that will be affected by the loss of intertidal habitat. The intertidal zone is very important for the benthic micro-algae that make up the microphytobenthos (MPB) because their abundance decreases subtidally as the increasing water depth restricts the penetration of light. In estuaries, MPB primary production rates can exceed those of the phytoplankton found in the overlying water column, to the extent that the MPB may be the major source of primary production in fine-sediment dominated hypertidal estuaries like the Severn (Underwood, 2010). They also have a role in biogeochemical cycling and sediment stabilisation. The peak concentration of MPB in the Severn is found between mid-tide and mean high water neaps. The loss of 76% of the intertidal area following construction of a Cardiff-Weston barrage could see a corresponding reduction of 77% in levels of MPB primary production (Underwood, 2010).

Habitat loss may, to some extent, be compensated for by other changes to the estuarine environment resulting from barrage construction. The altered sedimentary regime for example (discussed in full in a later section) could improve the carrying capacity of the remaining intertidal habitat, allowing the reduced area to support a greater population of birds than was previously possible (Warwick and Somerfield, 2010).

Waves and Currents

A tidal barrage will shelter the upstream area from swell waves (Wolf et al., 2009), as well as creating other local shelter and reflection effects. Local wave action may increase significantly where incoming waves interact with the outflows at sluices and locks (ABPMer and HR Wallingford, 2008). The high energy flows from sluices and turbine outlets will also lead to significant scour in the areas that surround them (Burrows et al., 2009a), which may prevent marine life from becoming established (Little and Mettam, 1994). Barrages will also affect the currents in the wider estuary, reducing the upstream flow speed (Burrows et al., 2009a). A Cardiff-Weston barrage could reduce the maximum tidal current in upstream areas by 45% (Xia et al., 2010).

The energy within a tidal flow is proportional to the cube of the velocity, so even small changes in current speeds may have significant implications. The altered tidal dynamics that result from barrage construction could increase stratification and reduce flushing rates, increasing the eutrophication risk (Burrows et al., 2009a; Wolf et al., 2009). Disruption of water flow also affects larval dispersal and the connectivity of communities (Bulleri and Chapman, 2009), and this may influence ongoing recruitment of organisms and the re-establishment of communities following barrage construction.

Sediment Dynamics

The energy of tidal currents is an important factor in determining the sediment dynamics within a marine system. This is of particular significance to estuaries such as the Severn, which are characterized by high levels of suspended sediment (Kirby, 2010). The reduced current flows upstream of tidal barrages are likely to cause an overall increase in subtidal deposition rates as fine sediments settle out of the water column (Underwood, 2010). There will, however, be local areas of increased current speed, in which sediment resuspension rates will also be increased (Wolf et al., 2009). The influence of a barrage on sedimentation patterns would also extend into seaward areas of the estuary (Warwick and Somerfield, 2010). The new sediment regime will not establish instantaneously, however, and there will be a period of enhanced sediment transport for months or even years after barrage construction (Burrows et al., 2009a).

The altered tidal regimes created by barrages, and the changes in sedimentation pattern they induce, are expected to affect benthic communities within the estuary. In the Severn, which has been most widely studied in terms of the potential effects of tidal barrages, the predicted post-barrage scenario would suggest an increase in the abundance of *Cerastoderma edule* (cockles) and *Mya arenaria* (clams), as well as small burrowing crustaceans (such as the mud shrimp *Corophium volutator*) and sedentary annelid worms (Warwick and Somerfield, 2010). Conversely, the populations of species such as the bivalves *Hydrobia ulvae* and *Macoma balthica* and the worm *Nephtys hombergii*, which are associated with dynamic regimes, are likely to decline. Overall, the benthic species richness, abundance and biomass are expected to increase (Warwick and Somerfield, 2010). Microphytobenthos are found in greater densities on fine sediments, and so their distribution and abundance would also be altered (Underwood, 2010).

Specific biogenic habitats of conservation importance such as *Sabelleria* (tube worm) reefs and *Zostera* (seagrass) beds may also be affected if sediment dynamics are altered (Parsons Brinckerhoff, 2008d). The effect of the raised water level and increased length of high water stand may expose intertidal areas to increasing wind-driven wave erosion, with implications for mudflats and saltmarshes (Pethick et al., 2009).

Water Quality and Pollution

Barrages are expected to reduce tidal flushing rates. A 40% reduction in flow rate could decrease the volume of water exchanged during a tidal cycle by 60% (Prandle, 2009). One potential implication of this is a decrease in upstream salinity (Wolf et al., 2009), although the likelihood of this occurring is contested (Kirby, 2010). Changes in salinity would affect the extent to which marine species are able to penetrate the estuary, with implications for their local abundance (Henderson and Bird, 2010). Littoral vegetation may also be affected, with reed beds replacing saltmarshes if the influence of freshwater extends further down the estuary (Pethick et al., 2009). It is also possible that there may be minor changes to upstream temperatures and pH levels (Parsons Brinckerhoff, 2008e).

Reduced tidal flushing has implications for the dispersal of nutrients and contaminants. Dissolved oxygen levels are expected to rise following the construction of a barrage (Kirby and Retière, 2009), but an increased concentration of dissolved nutrients such as nitrogen may also be observed (Parsons Brinckerhoff, 2008e). A rise in nutrient concentrations and decrease in suspended sediment could lead to a greater risk of eutrophication (Langston et al., 2010b). Discharged wastes could also build up landward of the barrage, (Parsons Brinckerhoff, 2008f), perhaps resulting in failure of environmental quality standards near outfalls (Parsons Brinckerhoff, 2008e).

Tidal power plants may directly introduce pollution into the system, from antifouling coatings or as a result of chemical leakage from either components such as the gearbox or from fuel or oil discharges from maintenance vessels (RGU, 2002). Increased pollution is also possible if contaminated material is reintroduced into the water column where sediment resuspension is increased during construction and the post-construction transition period or as a result of increased local currents (Burrows et al., 2009a). In the longer term, and across the wider estuary, the reduced tidal currents and reduced mixing that result will generally decrease resuspension of sediment and reduce the supply of contaminants (Prandle, 2009). The reduced water turbidity may also reduce the concentration of pathogens in the water column, as increased light penetration will increase the rates of photodegradation (Parsons Brinckerhoff, 2008e).

The clearer water may also improve conditions for suspension feeders (Warwick and Somerfield, 2010), by supporting an increase in phytoplankton biomass and primary production (Underwood, 2010). This will in turn increase the food supply for the benthos and so enhance the carrying capacity of intertidal areas for feeding shorebirds (Warwick and Somerfield, 2010), although any increase in food supply may not sufficiently compensate for the loss of intertidal habitat (Langston et al., 2010a). Changes in animal assemblages will also alter, for example, grazing patterns (Underwood, 2010) and so the process of attempting to accurately predict ecosystem outcomes following the construction of a tidal power plant becomes very complex.

Impacts on Society

Changes brought about following the construction of tidal power plants will also impact on society. The physical presence of a tidal power plant will affect other activities occurring in the area, which may include military exercises, oil and gas exploration, or other renewable energy opportunities. Marine aggregate extraction may also be affected, by changes to both substrate composition and tidal regime, as this may alter the timing of access periods (Parsons Brinckerhoff, 2008f). The suitability of dredge material disposal sites may also change, while telecoms cables, pipelines and outfalls may be affected by scouring, erosion or deposition (Parsons Brinckerhoff, 2008f).

Restriction of the ability of commercial and recreational vessels to navigate in the area due to obstruction, collision risk and reduced water depth could be a major implication of tidal power plants (Faber Maunsell and Metoc, 2007; ABPMer and HR Wallingford, 2008; Scott Wilson and EDF, 2010). Additional costs will be incurred if vessels are required to undertake longer journeys in order to navigate around renewable energy areas, and they will present greater hazards particularly for small and recreational craft. Conditions for small craft upstream of a barrage could potentially be improved, however, as a result of the longer high water stand (Burrows et al., 2009b) and the reduction in current speeds (Parsons Brinckerhoff, 2008f).

The presence of tidal power plants may prevent fishers from accessing traditional grounds, and bottom trawling or dredging may be further restricted in areas traversed by power cables (Faber Maunsell and Metoc, 2007). As discussed in earlier sections, the exploited fish populations may also be negatively affected by tidal structures, although the balance of the environmental impacts on commercial fish species is not known with any certainty. For example, the wider changes to sedimentation patterns in the Severn may ultimately increase the potential for commercial fisheries, as soft sediments could replace bedrock substrates seaward of the barrage (Warwick and Somerfield, 2010). Similarly, shellfish may be smothered by altered sediment regimes (Faber Maunsell and Metoc, 2007), or conditions for them within barrage basins may improve if reductions in water turbidity are not negated by the water quality issues associated with reduced flushing (Parsons Brinckerhoff, 2008f).

People will be disturbed by noise during both construction and operation, and the structure of a tidal barrage will present a significant visual impact (Parsons Brinckerhoff, 2008g). A barrage will also influence the wider seascape by creating a longer high water stand, reducing the intertidal area and associated habitats such as saltmarshes, changing the morphology and substrate on beaches, and increasing water clarity (Parsons Brinckerhoff, 2008f).

The coastal environment contains shipwrecks and other pieces of archaeological and geological heritage, which may be damaged, disturbed or destroyed as a result of the direct effects of tidal power installations and the cables associated with them (Parsons Brinckerhoff, 2008h; Faber Maunsell and Metoc, 2007; Aecom and Metoc, 2009). The indirect effects through alteration of hydrodynamics, shoreline morphology, water quality, tides, water level, and sedimentation regimes may also detrimentally affect underwater heritage (Parsons Brinckerhoff, 2008h).

Recreation and tourism are important activities within the coastal zone, and any negative effects on wildlife as a result of tidal power plants may have implications for nature tourism such as bird- and mammal watching (Parsons Brinckerhoff, 2008f; Faber Maunsell and Metoc, 2007). Tidal bores are also significant tourist attractions, especially that on the Severn, and would be lost following the construction of a tidal barrage (Parsons Brinckerhoff, 2008g). Upstream of a barrage, bathing may become safer as result of reduced currents, but the changes to the tidal regime may also affect bathing water quality (Parsons Brinckerhoff, 2008f). The tidal power plant itself may become a tourist attraction, as is the case for other large infrastructure projects. The Thames Barrier attracts about 200,000 visitors annually (Baker, 1991), and 350,000 people visit the La Rance tidal barrage each year (Kirby and Retière, 2009).

Tidal barrages could also bring ancillary benefits to society including road or rail links across the barrage and increased employment (Burrows et al., 2009b). A barrage could also provide flood defences, which could protect against both tidal and river flood risks (Burrows et al. 2009a). Conversely, flood risks could be increased as a result of saltmarsh erosion, the restriction of river outfalls by the longer high water stand, and the possible siltation of outfalls as a result of hydrodynamic changes (Parsons Brinckerhoff, 2008f). Flood risk, freshwater supplies and local land use patterns may also be affected by changes to the water table and groundwater flow (Environment Agency, 2002).

Mitigation of Environmental Impacts

Since the construction of the La Rance barrage in 1966, there have been significant developments that can reduce environmental impacts of tidal barrage. Advances in turbine design have occurred in the past 25 years, some of which are aimed specifically at environmental impact mitigations, such as the current emphasis on very low-head turbines (DECC, 2010d). It is possible for the turbines to be designed in such a way as to reduce the potential for pressure or contact injuries to fish (Turnpenny et al., 2000) and modern barrages are also likely to include passes so that migrating fish can avoid passage through the turbines in the first place. Such measures were not part of the design at La Rance (Kirby and Retière, 2009). Methods to prevent fish entering turbines include mesh netting, bubble curtains, flashing lights, and acoustic or electrical signals (Turnpenny et al., 2000). Devices including spillways over or under dam gates, fish ladders and fish lifts are also employed to assist fish passage past a barrage (Schilt, 2007).

The barrage walls can also be designed to allow more natural communities of marine life to become established. For example, natural materials such as coarse woody debris or even shellfish reefs can be incorporated into the construction, while recessing the mortar and leaving out the occasional block provides areas of refuge (Bulleri and Chapman, 2009).

The mode of operation of a tidal barrage can also reduce the environmental impact. Generalisation is difficult because the area of intertidal habitat lost as a result of changes to the tidal regime is very dependent on the bathymetry of the affected estuary, but modelling of five estuaries in northwest and southwest England suggests between 6% and 30% less intertidal habitat would be lost under two-way operation as compared to ebb-only generation (Wolf et al., 2009). Two-way generation also allows a more natural flushing regime (Prandle, 2009). The environmental benefits may not extend throughout the entire estuary, however, as a model has suggested that two-way generation could have more detrimental environmental effects than ebb generation on areas far upstream of a Severn barrage (Xia et al., 2010).

Tidal reefs also have environmental advantages over conventional barrages because the very low head requirement permits a more natural tidal regime to be maintained (Atkins, 2008). Tidal lagoons are also considered to be less environmentally damaging than barrages, as they do not obstruct the entire width of an estuary and can be sited so as to minimise loss of intertidal areas. However, lagoons require far greater quantities of construction materials than a barrage, and sourcing these aggregates has environmental and social implications (Crumpton, 2004).

Mitigation measures to reduce the environmental impacts of barrages have, to some extent, been costed. For example, the European Union Habitats Directive requires that developers impacting on protected habitats must pay compensation to ensure the protection of a similar ecosystem

(Treweek, 2009). Such compensation would add 1-5p/kWh to the cost of electricity from a Severn Barrage scheme (Parsons Brinckerhoff, 2008a).

There are also additional costs associated with technological approaches to impact reduction. Energy from two-way generation is about 10% more expensive than from ebb generation (Black and Veatch, 2007), and lagoons have higher constructions costs than traditional barrages as they require longer walls for a given enclosed area (Halcrow Group et al., 2009). The proposed Bridgwater Bay lagoon in the Severn estuary would provide about the same energy output as the Shoots barrage option, but would cost £1 billion more to build, making the unit price of delivered electricity about three times that of the barrage scheme (Parsons Brinckerhoff, 2008a). Lagoons are an untested concept, but the technology employed is mature. There is, therefore, little chance of the costs of lagoons reducing over time, although any actual experience of their operation will provide more accurate cost estimates (SDC, 2007).

Conversely, tidal reef schemes use less than materials than conventional barrages, and it has been proposed that a reef on the Cardiff-Weston site could be both cheaper and produce more energy than the corresponding barrage option (Atkins, 2008). As reefs remain a theoretical concept, the economics of such schemes are still uncertain (Atkins, 2008; Halcrow Group et al., 2009). Tidal fence schemes, which comprise an open row of tidal current turbines instead of a barrage wall, are similarly unproven, but one cost estimate suggests that an equivalent fence would produce energy at a price of at least 40p/kWh, which is more than three times that predicted for a conventional Cardiff-Weston barrage (Parsons Brinckerhoff, 2008a).

2.5 Summary

Tidal power has some major advantages other offshore renewables such as wind and wave because it is predictable and, as the time of peak power varies for different locations, has the potential to contribute to base load. Also, tidal barrages remain the only marine energy technology that has been proven to supply significant quantities of electricity. However, tidal barrages have the potential to impact, both positively and negatively, on a wide range of ecological and social parameters. The loss of intertidal habitat resulting from raised water levels is one of the most significant environmental impacts, and schemes such as tidal lagoons, reefs and fences have been proposed to reduce the scale of negative impacts.

The next chapter will propose a novel methodology for assessing these diverse impacts using an ecosystem services approach, with a view to facilitating the economic valuation of the changes resulting from a barrage development and thus supporting planning decisions.

3 A Methodology for the Assessment of Local-scale Changes in Marine Environmental Benefits

3.1 Introduction

Assessing trade-offs between conflicting uses is an integral part of decision-making in natural resource management. Improving the transparency of the decision-making process, and the effectiveness of its outcomes, requires assessment of the wider environmental and social costs and benefits of changing uses. This need to better assess the ramifications of ecological impacts is at the core of the ecosystem services approach, which highlights the inter-linkages between the different components of an ecosystem and how these relate to human welfare.

Considerable effort has been applied in developing typologies and conceptual frameworks for the assessment of ecosystem services, and this chapter begins with a review of this literature. The conceptual frameworks consider a large suite of services and benefits, suggesting that the ecosystem services approach is well placed to support local-scale planning decisions, which are required by the existing Environmental Impact Assessment (EIA) process to take account of the implications of a development on a range of environmental and social factors. To date, however, empirical assessments at a local-scale within the marine environment have tended to focus on a single or limited set of services, and so provide little insight into the feasibility of undertaking more comprehensive evaluations. It is important to provide examples that support proof of concept at a local-scale (as well as at the broader scales of, for example, the UK National Ecosystem Assessment (2011)), in order to determine the practicalities of attempting to embed ecosystem service approaches into the local planning process.

This chapter therefore proposes a methodology for conducting an Environmental Benefits Assessment (EBA) that considers how the identification and quantification of a comprehensive suite of marine ecosystem benefits might proceed in practice, and how such assessments could complement EIAs as a tool for planning local-scale coastal developments. The EBA methodology is consistent with the ecosystem services framework, and does not propose a conceptual shift. Instead, its purpose is to suggest practical steps for assessing environmental benefits in order to advance the development of methods for applying ecosystem service approaches at a local scale. It focuses on the quantification of benefits (as opposed to services) because this links more closely to the subsequent step of valuation, making the EBA approach a useful precursor to cost-benefit analysis, or other forms of value-based policy assessment. This focus on quantifying benefits does not preclude extension of the method to include evaluation of the underlying services. However, taking a 'top-down' approach is pragmatic, as the development of indicators for marine ecosystem services remains an ongoing task.

In the context of this thesis, the EBA approach is used to identify the multiple benefits provided by the Taw Torridge estuary in North Devon, and to consider how these benefits could be affected by the construction of a tidal barrage. Tidal barrages are a highly topical, novel use of the marine environment and (as reviewed in Chapter 2) provide a good example of conflicts between environmental impacts and economic and social benefits. The EBA process will also help to identify a suitable focus for the empirical valuation that will form the main component of this thesis.

The Taw Torridge was selected as the case study site because it is a viable site for tidal power; over the past twenty years, the possibility of constructing a tidal barrage in the Taw Torridge has been raised repeatedly. However, the most recent proposal for a barrage was in 2008, and the lack of an active feasibility study was thought to reduce the risk of public announcements while the research was underway that could influence the outcome of the research. During the course of the research, feasibility studies for both the Severn and Mersey concluded with the announcement that the barrages would not go ahead at that time, suggesting that this precaution was sensible.

Time and cost limited the scope of the assessment to a desk-based study of the type and scale of environmental benefits provided by the estuary, although this was sufficient for an initial test of the EBA approach proposed. The study relied heavily on grey literature, unpublished primary data supplied by statutory agencies, and personal communications. Peer-reviewed studies were used where available. Quantification and modelling of the potential impacts of a barrage on these benefits was also beyond the scope of the study, and so a qualitative scale was used to indicate the predicted scale and sign of the impacts. Further details of the environmental benefits provided by the Taw Torridge can be found in Appendix I: A table summarising the main findings is presented within this chapter.

3.2 The Evolution of Ecosystem Service Frameworks

Scientific evidence and public concern has increased awareness of the need to improve the sustainability of resource use. Environmental protection legislation is now commonplace, and Environmental Impact Assessments are a statutory requirement for a vast array of public and private projects in the UK that include agriculture, transport, energy, industry and tourism (HMSO, 2000). The decline in species and habitats continues nonetheless, as highlighted by the State of Nature Report (2013), which states that 60% of UK species have declined in the past 50 years, and one in ten are under threat of extinction.

One reason that policy decisions continue to overlook social and environmental externalities is because they are not readily quantified in terms that permit their direct comparison with the exploitation of manmade capital (Costanza et al., 1997; Barbier, 2007). In response to this, the ecosystem services approach has evolved, and aims to provide a common language and a transparent framework for quantifying the ecological, social and economic trade-offs that must be evaluated in development decisions (Granek et al., 2009). The philosophical foundations of the concept date back to the eighteenth and early nineteenth centuries (Mooney and Ehrich, 1997), but recent interest in the approach began to gain particular momentum in the late 1990's. Work by Daily (1997) and Costanza et al. (1997) was significant in drawing wider attention to the concept and its applications.

The ecosystem services concept is an anthropocentric approach to resource management. It applies a utilitarian philosophy, in which the value people place on ecosystems is derived from the utility (or preference satisfaction) that the natural world provides (Bateman et al., 2011). Common to many discussions of ecosystem services is an attempt to visualise the concept as a linked chain between the structures and processes that support the ecosystem through to the end-point of human benefit, to which a value can be ascribed (Figure 5).

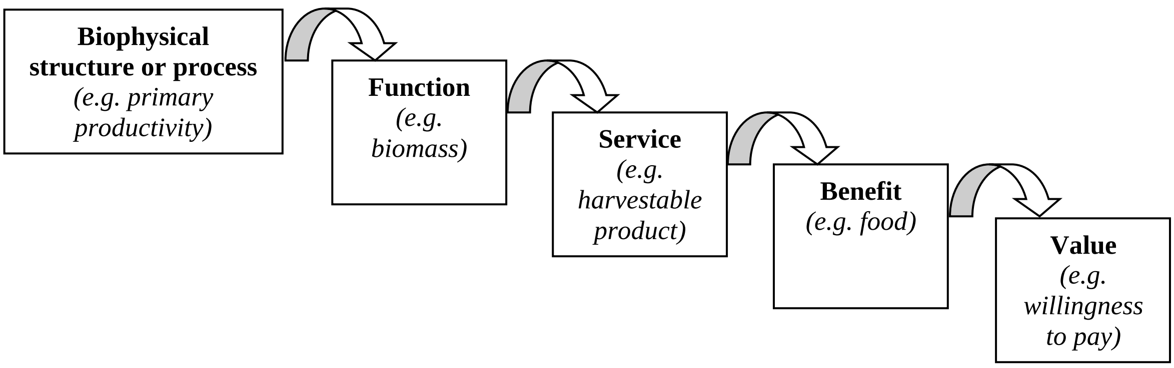

Figure 5. A framework for visualising ecosystem services and related concepts (adapted from Haines-Young. and Potschin, 2010.)

Ecosystem services approaches, and the subsequent step of environmental valuation, are becoming increasingly utilised, and classification frameworks for ecosystem services have taken several forms. Greater consensus began to develop after Costanza et al. (1999) proposed a framework for valuing the goods and services provided by the oceans, which contained seven main categories: gas and climate regulation; disturbance regulation/erosion control; nutrient cycling/waste treatment; biological control/habitat/genetic resources; food/raw materials; recreation/culture; and transportation/security. Subsequent assessment frameworks have tended to utilise a similar form of classification, which defines services according to the type of function they perform.

This type of functional classification was the basis of the Millennium Ecosystem Assessment (MEA) (2003). The MEA proposed a tiered system, which classified services such as nutrient cycling and primary production as supporting services, upon which the production of all other ecosystem services depend. These other services were classified as provisioning services (food, genetic resources and other raw materials), regulating services (such as climate regulation and water purification) and cultural services (which include recreation, education and cultural heritage). The MEA classification is useful as a tool to aid understanding of the range of services and benefits ecosystems provide to people. It presents them in a straightforward way that is both simple to understand while at the same time indicating the underlying complexity of ecosystems, where services are inter-dependent (Fisher et al., 2009). Several authors have adopted the MEA classification in marine ecosystem service assessments, for example studies by Beaumont et al. (2006, 2007); Everard et al. (2010); Hussain et al. (2010); and Remoundou et al. (2009).

However, other authors accept the conceptual clarity of the MEA classification, but question its usefulness as a framework for the operational assessment of ecosystem services (Wallace, 2007; Costanza, 2008; Fisher et al., 2009). The MEA has been particularly criticised for its definition of ecosystem services as “the benefits people obtain from ecosystems”. This is not compatible with the development of frameworks which seek to clearly distinguish between services and benefits as it is the latter, not the services that provide them, which should be valued (Boyd and Banzhaf, 2007; Fisher et al., 2008).

Clearly defining the point at which to apportion value is important in order to reduce the risk of double counting, which can arise if the total ecosystem value is derived from aggregation of all the different ecosystem components. For example, adding the separate values for nutrient function and biodiversity risks double counting the value of the nutrient function that is ‘captured’ within the overall biodiversity value (Ledoux and Turner, 2002).

This risk of double counting had led authors to question whether supporting services should be included at all in frameworks for ecosystem service valuation (Fisher et al., 2008). Certain services provided by ecosystems have a direct link to the benefit obtained from them by people: the production of food, for example. Ecosystems also provide services such as primary production, which are fundamental to the operation of the ecosystem (and hence to the supply of other services and benefits), but which are not, themselves, directly utilised by people. Whether it is useful, operationally, to define as “services” all the inputs and interactions which at some point, however indirectly, provide human benefit is contested. It is argued that only those directly yielding human well-being should be considered as services for the purposes of valuation (Boyd and Banzhaf, 2007; Wallace, 2007). The framework proposed by The Economics of Ecosystems and Biodiversity (TEEB, 2010), for example, defines most of the services classified within the MEA’s supporting category as underlying ecological processes.

However, considering as “services” only the final tier of beneficial processes risks the failure to appreciate the value of less apparent ecosystem services. It is the indirect nature of the links between human benefits and many ecosystem functions that has been responsible for ecosystems being undervalued to date (de Groot et al., 2002). Overlooking the supporting services may limit the effectiveness of management strategies and contribute to ecosystem degradation (Beaumont et al., 2008; Ledoux and Turner, 2002). Expanding the definition of services to include the supporting functions also highlights the importance to human welfare of the integrity of the ecosystem as a whole (Fisher and Turner, 2008).

A typology has been proposed to recognise the need to identify ecosystem endpoints to facilitate valuation, while still maintaining a broad definition of ecosystem services. This employs the term "final" services to identify those which provide direct benefits (Boyd and Banzhaf, 2007; Fisher and Turner, 2008). Services from which people benefit only indirectly become "intermediate" services (Fisher et al., 2008), which are analogous to the "supporting" services of the MEA (2003). This approach has been adopted by, for example, the UK National Ecosystem Assessment (2011). Developing a universal classification to distinguish between final and intermediate/supporting services remains problematic, because whether a service is supporting or final depends on the context. For example, unpolluted water is a final service to a bather, but an intermediate service to a consumer of shellfish.

A final area of contention is the interpretation of the term 'ecosystem'. Balmford et al. (2008) proposed a framework to take account of the distinction between services and benefits, which was adapted specifically for the marine environment by Saunders et al. (2010). This classification presented a departure from other frameworks in its broad definition of ecosystem benefits. Previous work had included only benefits that were derived from the ecosystem in its strict ecological sense, while Balmford et al. (2008) and later Saunders et al. (2010) chose to include benefits from the abiotic environment, such as the use of space for transportation and the production of salt and energy.

The argument for the inclusion of services provided by abiotic parameters alone seems compelling when the purpose of an ecosystem service assessment is to consider the consequences of a specific local intervention. Waterways and the availability of energy, for example, can provide benefits, and the realisation of these benefits may be impacted by any new marine development, something recognised within standard Environmental Impact Assessments. The failure of ecosystem service assessments to consider abiotic benefits in this context would result in inadequate treatment of all relevant issues.

Ecosystem service frameworks continue to evolve. Further refinements to service classifications have been suggested under, for example, the Common International Classification of Ecosystem Services (CICES) (Haines-Young and Potschin, 2013), and the inclusion of cultural services has been the topic of a recent debate in the literature (Daniel et al., 2012; Kirchoff, 2012; Chan et al., 2012). Alternative conceptual frameworks continue to be proposed, such as a capabilities concept that takes a less utilitarian view of benefits and wellbeing (Polishchuk and Rauschmayer, 2012), and the Ecosystem Properties, Potentials and Services (EPPS) framework, that aims to better link management practices with ecosystem functions, their potential to provide benefits and the actual contribution made to human wellbeing (Bastian et al., 2012). Other methods to more closely connect ecosystem service approaches to management needs include a framework for trade off analysis to assist ecosystem-based management of marine areas (Lester et al., 2013) and the inclusion of ecosystem services within the Drivers-Pressures-State-Impact-Response (DPSIR) framework (Atkins et al. 2011), which is commonly used in natural resource mangement.

The operational usefulness of conceptual frameworks can only be determined by applying them in the field. Conceptual frameworks include a broad suite of ecosystem services, but empirical research tends to focus on services individually or in a limited set (Rees et al., 2012; Mangi et al., 2011; Luisetti et al., 2011; Pittock et al., 2012; Balvanera et al., 2006). Further studies that attempt simultaneous assessment of large suite of ecosystem services are necessary to aid development of the ecosystem services approach, as lessons learned from such practical application will help to refine further the conceptual frameworks.

3.3 Developing a tool for local environmental impact appraisal

One of the challenges in developing a universal framework is that there are many contexts in which ecosystem service assessments can be applied. These include national-level environmental accounting, the development of regional or sectoral resource management policies, and to support local planning decisions. The different ecosystem contexts also present their own challenges to a universally applicable framework, in terms of the different services provided, the availability of data and the interaction between ecosystem components at different scales. The context of this research is to evaluate the potential for ecosystem service assessments to support decision-making with respect to a specific local-level intervention affecting an estuarine environment.

Appraisal of the environmental impact of a development is currently governed by the Strategic Environmental Assessment (SEA) Directive (Directive 2001/42/EC) and the Environmental Impact Assessment (EIA) Directive (Directive 2011/92/EU). SEAs apply to public plans and programmes, while EIAs are required for individual projects, but both are procedures that seek to ensure that environmental implications are appropriately considered in decision-making.

The SEA and EIA Directives are conceptually well aligned with the ecosystem services approach since they consider the environment as more than its ecological parameters, and contain explicit reference to the need for evaluations to consider people, material assets and cultural heritage. A

SEA was carried out as part of a recent feasibility study on a potential Severn Barrage (Parsons Brinckerhoff, 2010), and further guidance for compiling EIAs for tidal barrages has also been produced (Environment Agency, 2002). Both sources include reference to the impacts on certain environmental benefits such as noise, visual amenity, recreation, flood protection, fisheries, and archaeological features. In the Severn SEA in particular, the list of significant issues is extensive.

However, in categorising the parameters to be assessed, the approach taken in the SEA and EIA guidance in evaluating tidal barrages has not been systematic. The categorisation used within both the SEA (Parsons Brinckerhoff, 2010) and EIA guidance (Environment Agency, 2002) causes duplication, with, for example, noise, flood risk and water quality listed as significant issues in more than one SEA topic, and visual amenity appearing in two EIA categories.

Also, the SEA approach as applied to the Severn Estuary does not lead easily to the step of valuation, which could facilitate decision-making by quantifying the impacts using a common metric. This is because no distinction is made in presenting information on ecosystem processes (such as saltmarsh functionality), services (including water quality) and environmental benefits (for example availability of commercial fish species), and so it is not immediately apparent for which of the parameters detailed valuation should be attempted.

This suggests that there is scope to more closely embed an ecosystem services approach within the local-scale planning framework, to ensure a systematic and comprehensive treatment of the full range of benefits likely to be affected, and to facilitate the additional step of valuing these benefits to allow their quantification in a common metric. The Environmental Benefits Assessment methodology proposed below suggests how this process of more closely linking the EIA and ecosystem services approaches could begin in practice.

3.4 Proposed Methodology for an Environmental Benefit Assessment (EBA)

The first stage of an Environmental Benefit Assessment (EBA) is to characterise the site and identify stakeholders as this is fundamental to gaining an understanding of the benefits delivered prior to the proposed development. The current situation is then described through i) compiling an inventory of the environmental benefits obtained from the site; ii) quantifying the current level of delivery of each benefits; and iii) determining their relative importance. The change in the level of delivery of the environmental benefits as a result of proposed development is then examined. These steps are described in more detail below.

Definitions

The proposed methodology follows Balmford et al. (2008) and Saunders et al. (2010) by including services provided solely by the abiotic elements of the environment as well as those with an ecological basis. This ensures that the assessment can accommodate all the potential implications of a proposed infrastructure development within a single process. This is in line with the SEA/EIA process, which considers benefits such as transport. The term ‘environmental services’ is used to describe this extended classification of services, and will be defined as the conditions and processes through which natural ecosystems, and the species and abiotic characteristics that make them up, sustain and fulfil human life (adapted from Daily, 1997).

The methodology seeks to identify and quantify benefits (as opposed to the services that provide them), because it aims to facilitate ecosystem valuation. Operationally, ecosystem valuation is much simplified by considering only the ecosystem endpoint that yields a valuable benefit and not the complex processes by which it was provided, as measurement of the latter is much more complex (Boyd and Banzhaf, 2007). Definitions that clearly distinguish between services and benefits are essential (Fisher et al., 2009), and it has been suggested that the separate term ‘ecosystem benefit’ could be explicitly defined and applied within valuation frameworks to reflect this (Wallace, 2007; Fisher and Turner, 2008). The proposed methodology will therefore also use the term ‘environmental benefit’, which is defined as the point at which a direct gain in human welfare provided by environmental services is realised (adapted from Fisher et al., 2009).

Site characterisation and identification of stakeholders

The concept of environmental benefits is anthropocentric, and so at the outset of any assessment it is important to understand the social, economic and cultural issues within the local area, as these are integral to the realisation and perception of environmental benefits. Such understanding is gained by collating information on the socio-demographic characteristics of the local population, land use, economic activity and employment, as well as the environmental characteristics of the area (including existing environmental protection measures). Understanding the character and use of the area helps to identify stakeholders (organisations and individuals) from whom specific information can be sought. These stakeholders will not all be local, as there will be regional and national interest in the area.

Identifying relevant environmental benefits

A comprehensive inventory of the environmental benefits provided by the site is required at the start of any assessment, so that the full scope of potential impacts can be understood. The environmental benefits provided may be realised or transferred elsewhere (for example, carbon sequestration and the health benefits of recreation), but the EBA is concerned with the implications of a development on the supply of benefits from the local site. Local knowledge is essential in compiling an environmental benefits inventory for a particular site, requiring consultations with local stakeholders and examination of any relevant grey literature.

The creation of an inventory is facilitated by a classification framework providing a coherent categorisation of environmental benefits. This methodology applies a typical ecosystem services framework, arranged to facilitate operational assessment in a specific context rather than provide examples to illustrate a concept. The foundation of the framework was the definition of the types of values responsible for benefit provision. This permits the inclusion of existence, bequest and option values, which form part of the Total Economic Value of an ecosystem (Barbier 1994; Figure 6), and also serves as a precursor to an ultimate valuation stage. For example, market prices are available for many benefits with direct use values, whilst costs to avoid or mitigate damage are often used to determine indirect use values, and stated preference techniques are required to elicit non-use values.

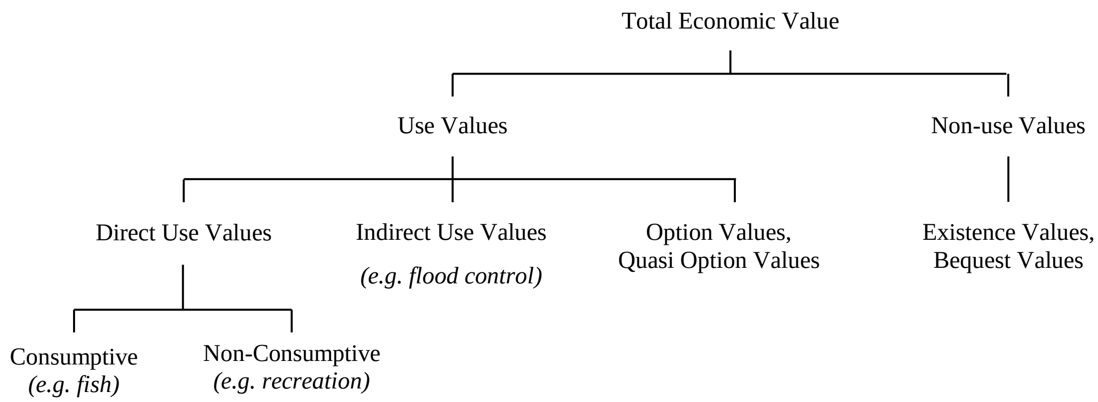

Figure 6. A classification framework for ecosystem services according to type of economic value obtained (from Barbier, 1994; Turpie, 2003.)

The value categories were then mapped onto environmental service types, as the established typologies provide a comprehensive characterisation of services that prompts the compilation of an extensive inventory of benefits. The Millennium Ecosystem Assessment (2003) typology of provisioning, cultural and regulating services was used, but supporting services were omitted, as they do not directly provide environmental benefits. An additional category of carrier services was, however, included (after De Groot, 2006), to describe the provision of space for infrastructure or transport. These broad service types were then subdivided into categories of benefits (after Beaumont et al., 2008; Balmford et al., 2008; Saunders et al., 2010). The inventory is completed by listing, within the relevant categories, all the specific benefits provided by the site. The expected benefits from a UK macrotidal estuary have been used as an example to illustrate how the inventory is to be populated (Table 2).

Table 2. An environmental benefits inventory for a generic UK macrotidal estuary

Type of value	Service type	Benefit/Value category	Examples of specific benefits
Direct Use (consumptive)	Provisioning	Food	Fish, shellfish, marine plants and algae
		Raw materials	Bait, aggregates, industrial products, biofuels
Direct Use (non-consumptive)	Carrier	Provision of space	Transport, mooring, energy installations
	Cultural	Recreation and tourism	Nature watching, angling*, watersports
		Cognitive development	Education, research
		Heritage and identity	Archaeology, cultural heritage
		Psychological wellbeing	Visual amenity, inspiration
Indirect Use	Regulating	Contaminant control	Clean water and air
		Disturbance prevention	Flood and erosion control, climate regulation
Non-Use		Existence, Bequest	Knowledge that adequate habitat is available locally and will continue to be so in future
Future Use		Option	Availability for alternative future uses

* This refers to the enjoyment of the activity. The consumption of any catch is classified separately as food.

Quantifying the current level of benefit delivery

A more detailed evaluation of the individual benefits listed within the inventory is then required, the first stage of which is to identify appropriate metrics by which each benefit can be effectively quantified, and then to use these to determine the level at which the benefit is currently delivered. An Environmental Benefits Assessment is concerned primarily with the human perspective, and so much of this data must be obtained directly from the beneficiaries. It is likely that some data (fisheries and tourism statistics, for example) is already collected and held by statutory and other agencies. Other data sources include grey literature and peer-reviewed articles.

Evaluating the importance of the environmental benefits

As Table 2 illustrates, the list of potential benefits provided by a particular ecosystem is likely to be extensive, and, in the absence of monetary values, the different benefits will be quantified using different metrics. To aid preliminary evaluation, and help to inform how effort should be focused when quantifying the changes resulting from the proposed development, the importance of each benefit can be represented on an ordinal scale (high, moderate or low). Objective importance criteria are likely to be absent for many environmental benefits, so this qualitative assessment needs to be based on discussions with stakeholders that consider factors such as the number of beneficiaries and degree of management concern.

Quantifying changes in benefit delivery as a result of the proposed development

The final stage of the assessment is to consider the potential environmental impacts of the development, and to use this to deduce the expected change in each environmental benefit following the development. Environmental impact information can be obtained from strategic and project-specific environmental impact assessments, peer-reviewed and grey literature, and expert opinion. These changes should be quantified, indicating the levels of uncertainty.

The current level of, and predicted changes to, each environmental benefit can be reported in the original measurement metric (such as weight of fish landed or number of participants). However, this will result in the changes in benefit delivery being reported in a range of metrics. Performing the additional step of monetary valuation would standardise the metric used, making more apparent the relative significance of impacts on the different benefits. Tools such as multi-criteria analysis can be used to support decision-making in situations where monetary valuation of the environmental benefits has not been, or cannot be, undertaken.

3.5 Case Study: Tidal Power in the Taw Torridge Estuary

The Taw Torridge Estuary

The Taw Torridge estuary is in North Devon in the southwest of England (Figure 7). It is the confluence of the Taw estuary which runs east-west through Barnstaple to its tidal limit at SS 4750 2100 (near Bishops Tawton), and the Torridge, which runs north-south through Bideford to its tidal limit at SS 5695 2825 (near Weare Giffard). The estuaries converge near Instow and share a joint mouth, flowing out into Bideford Bay.

Tidal Barrage Proposals

The Taw Torridge estuary has a tidal range of 7.5m at its mouth (UK Hydrographic Office, 2009), making it a potentially viable site for a tidal barrage. Tidal energy is not a new proposition for the estuary; there was a tidemill at Instow, which operated from at least 1797 until the mid-1800s, when it was closed down to make way for the railway (Grant, 1999). An early offer to construct a tidal barrage for electricity generation was made by the American military, which had used the estuary for training during World War II (Butterworth, 2010).

More recent proposals for a tidal barrage stemmed from an assessment conducted by Binnie and Partners (1989), who, as part of renewed interest in a Severn Barrage scheme, were commissioned by the UK Government to assess the tidal power potential of small estuaries around the UK coast. Scotland and the east coast of England were excluded from the study due to insufficient tidal range, but 118 estuaries and embayments on the west coast of Wales and England and the western part of England's south coast were assessed. The evaluation of criteria such as mean tidal range, water depth, basin area, and potential cost of energy reduced this list to 9 sites that were considered attractive locations for tidal barrages. One of these was the Taw Torridge estuary, where two barrage sites were deemed potentially feasibly: across the mouth between Airy Point and Northam Burrows and across the Taw from Crow Point to the northern end of Instow sands (Figure 8).

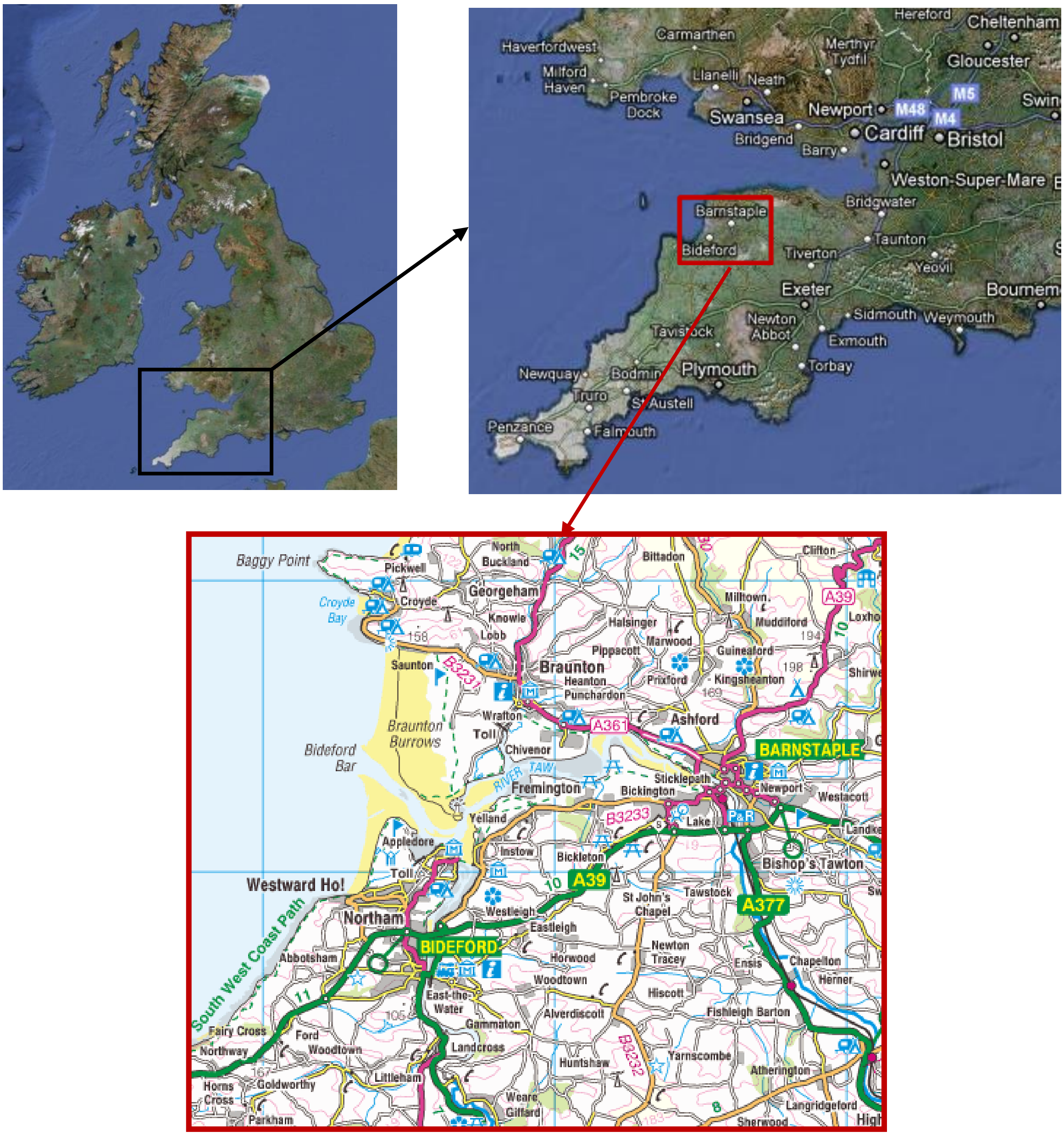

Figure 7. The location of the Taw Torridge Estuary

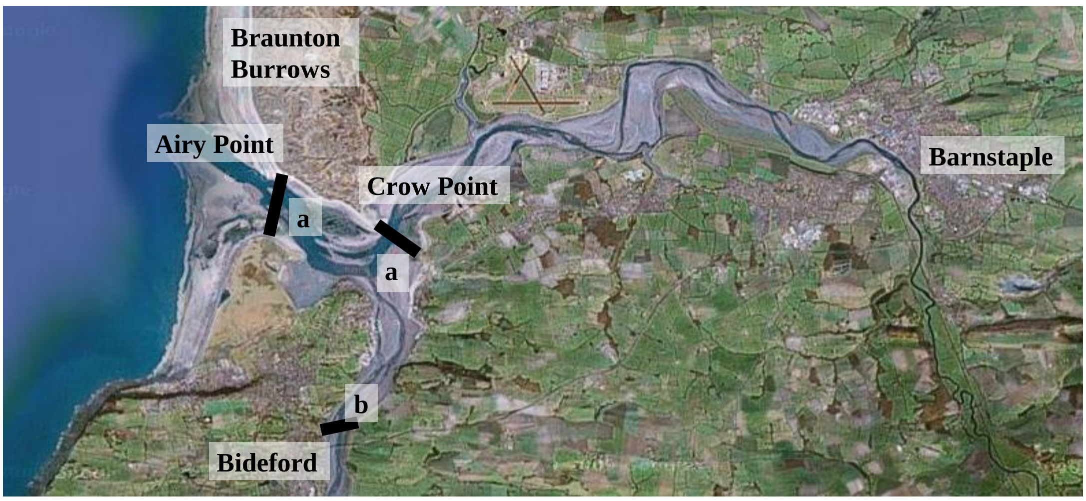

Figure 8. Proposed sites for tidal barrages in the Taw Torridge estuary: (a) from Binnie and Partners (1989), and (b) from SWEB and ETSU (1993)

During the 1990s, the local electricity generating board also considered possibilities for a barrage across the Torridge, near the site of the new A39 road bridge (SWEB and ETSU, 1993) (see Figure 8). At a similar time, barrage options at the two sites proposed by Binnie and Partners (1989) were put forward by a private company, who revived the submission in 2008 and again in 2013. More informal suggestions for barrages upstream in the Taw have also been made (Day, 2010; Pitcher, 2010). No formal planning applications for a tidal barrage have yet been submitted.

The recurrent pressure on the local authorities to consider a tidal barrage scheme was noted in the latest Estuary Management Plan (Northern Devon Coast and Countryside Service, 2010), in which it was suggested that a feasibility study was needed to provide guidance for future planning applications. A tidal barrage from Airy Point at the mouth of the estuary (Figure 8) would utilise the largest tidal prism and so produce the most energy, but in practice it seems unlikely that this would be chosen as an actual barrage site, as any such construction would impact heavily on the UNESCO Biosphere Reserve at Braunton Burrows to the north, and its feasibility would be questionable given the continued erosion of the shoreline at the estuary mouth.

Instead, the assessment of potential barrage impacts is based on a barrage at Crow Point. The Taw is potentially a more attractive proposition than the Torridge, as it has a larger tidal prism, and also the passage of commercial shipping and fishing vessels into Bideford and Appledore would not be affected. Located on the edge of Braunton Burrows, a barrage at Crow Point would undoubtedly have some impact on the UNESCO reserve but would be much reduced compared to an Airy Point barrage. Any impacts on Braunton Burrows or terrestrial systems have not been considered further, as the focus of the study is marine ecosystem services. Using a site further upstream in the Taw would have similar marine environmental impacts to a barrage Crow Point, particularly those related to upstream water quality and passage past the barrage by marine animals and ships. Impacts such as habitat loss, which relate to the area of estuary enclosed, would be mitigated to some extent if the barrage were moved upstream, as the size of this affected area would be reduced.

Empirical Environmental Benefits Assessment

Site characterisation and identification of stakeholders

An important group of stakeholders and beneficiaries are those living in the closest proximity to the Taw Torridge estuary system, which, for the purpose of this study, was chosen as the area within about 20km of the convergence of the rivers. The selection of this area includes the tidal limits of both rivers and the main population centres of the area. The area is rural and economically deprived, and the local population is predominantly white and older than the national average (Table 3). Individual stakeholders consulted included: councils, statutory agencies, watersports clubs, arts organisations, fishermen and fisher associations, conservation organisations, utility companies, the harbour master, a large shipyard, the Royal Marines, and a business forum.

Table 3. Selected demographic characteristics of the population living within 20km of the Taw Torridge estuary

Characteristic	Measure	References
Population size	100,000 people	ONS, 2001
Urbanisation	Low compared to the national average, but locally high in the immediate proximity of the Taw Torridge	Environment Agency, 2008
Ethnicity	99% white	ONS, 2001
Age structure	Median age is 45.5, compared to 40.0 for the South West region and 37.0 for the national average	ONS, 2001
Land use	Predominantly grass and pasture, reflecting the widespread cattle and sheep farming	Environment Agency, 2008 DEFRA, 2007
Unemployment	Unemployment rates are higher than regional and national averages	Devon County Council 2006a,b
Earnings	Wage rates are 21% lower than the national average	Nankivell, 2010
Economic drivers	A higher proportion of the population are employed in tourism, agriculture and fishing compared to regional and national averages. In absolute terms, the latter sectors are relatively small, while tourism supports over 20,000 jobs, and was worth £375 million in 2008.	ONS, 2001 Northern Devon Partnership, 2009 Nankivell, 2010

Much of the estuary and its coastline has some degree of statutory environmental protection. There are four Sites of Special Scientific Interest (SSSI) within, and adjacent to, the estuary (Figure 9), which were designated for bird and plant life, coastal habitats and geological landforms (Natural England, 2001a, b). Additional protection of estuary sites predominantly relates to the sand dunes at Braunton Burrows, which is both a Special Area of Conservation under the Habitats Directive (JNCC, 2002) and forms the core zone of a UNESCO Biosphere Reserve (UNESCO, 2009). The whole estuary is included within the buffer zone of the Biosphere Reserve (North Devon Coast and Countryside Service, 2008). The coastline on both sides of the estuary mouth is also within the North Devon Area of Outstanding Natural Beauty (North Devon AONB Partnership, 2009).

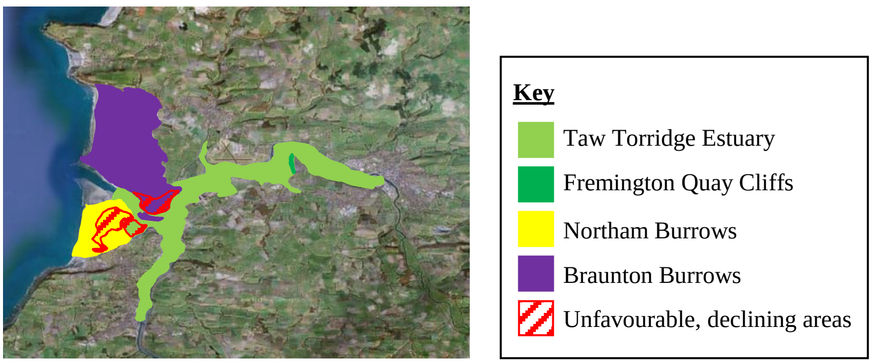

Figure 9. Sites of Special Scientific Interest (SSSIs) within, and at the mouth of, the Taw Torridge estuary, highlighting those areas in an unfavourable and declining condition (from Natural England, 2010).

Identifying relevant environmental benefits

The Taw Torridge provides a range of environmental benefits derived from provisioning, carrier, regulating and cultural services. A summary of the information is presented at the conclusion of the narrative section below (Table 4) and further details are provided in Appendix I.

Quantifying the current level of benefit delivery

The collection of empirical data from the Taw Torridge was beyond the scope of study. Secondary sources (grey and peer-reviewed literature, unpublished data from statutory agencies, and personal communications) enabled at least partial quantification of 12 of the 31 benefits listed, although there is a low confidence level associated with much of the data (Table 4). The confidence level was allocated depending on the source of the data, how recently it had been collected, and its scope (i.e. whether it considered the entire estuary or sector, or was a partial assessment).

The Taw Torridge has one of the largest natural mussel stocks in the South West (TTEP, 1998) and has eight designated bivalve production areas (Food Standards Agency, 2010), but it is not extensively exploited due at least in part to recurrent water quality issues (TTEP, 1998; Food Standards Agency, 2010). Netting for salmon and sea trout continues in the Taw Torridge, but is being phased out (CEFAS and Environment Agency, 2010), and a small number of small-scale commercial fishers use drift nets for bass and mullet within the estuary. The open sea beyond the estuary supports more significant fisheries. Skates and rays (Rajidae), squid (*Loligo spp.*), bass, (*Dicentrarchus labrax*), whelks (*Buccinum undatum*), lobsters (*Homarus gammarus*) and flatfish (particularly sole (*Solea solea*) and turbot (*Scophthalmus maximus*)) are particularly important in the catches landed at local ports (MMO, unpublished data).

There is no commercial shipping using the Taw: the power station and oil terminal are no longer operational and siltation has affected navigation further inland. The quays at the mouth of the Torridge handle a relatively low volume of commercial shipping (Bideford Harbour Master, unpublished data; Torridge District Council, 2010) and a passenger ferry to Lundy Island runs regularly during the summer months (Lundy Island, 2010). The Taw and its beaches are used extensively for military amphibious craft training.

It has been estimated that tourism supports over 20,000 jobs (Northern Devon Partnership, 2009), and was worth £375 million to the economy in 2008 (Nankivell, 2010). During the holiday season, tourism causes a threefold increase in population (Northern Devon Partnership, 2009), indicating the importance of tourists as beneficiaries of ecosystem services. The relative importance of the estuary and coastal area to tourism is difficult to assess as there have been few detailed studies of recreational use of the Taw Torridge. It has been estimated that watersports directly contributed

£80 million to the turnover of businesses in northern Devon in 2008, with 149,000 visitors attracted, at least in part, by local watersports opportunities (Abell and Bromham, 2009). An indication of the relative popularity of different recreational activities taking place within the estuary can be gleaned from the membership of local clubs and organisations, which suggests that angling and sailing are particularly well subscribed. Nature watching is also poorly quantified, although the estuary provides opportunities to observe otters and occasional marine mammals. Eighty eight waterbird species including rare visitors to the UK such as the spoonbill (*Platalea leucorodia*) have also been recorded in the estuary (Calbrade et al., 2010).

Schools and field studies centres make educational visits to the estuary, and academic interest in the Taw Torridge is similar to that for other small estuaries in the region, although considerably less than for major, well-studied estuaries such as the Severn and Tamar. The Taw Torridge estuary contains many features of archaeological interest (Preece, 2008), including two scheduled ancient monuments (Planning Policy Unit, 2003; TTEP, 1998). Shipbuilding and fishing are extremely important to the heritage of the area (Preece, 2008; Farr, 1976; Oppenheimer, 1968; Rogers, 1938), and maintaining links to this heritage supports local tourism.

The cultural heritage and the environment of the area inspire individual artists, although the best known contribution of the Taw Torridge to the Arts remains as the inspiration for *Tarka the Otter*, the novel by Henry Williamson, which was first published in 1927. The estuary and its adjacent open coastline provide a varied seascape, with mud and sandflats, sandy and rocky shores, and the extensive dunes of the Braunton Burrows.

The estuarine habitats (particularly the areas of saltmarsh and mudflat and the shellfish beds) can contribute to the provision of clean water by sequestering pollutants. Bathing and shellfish water quality are monitored at specific sites within the estuary (Environment Agency, 2010; Food Standards Agency, 2010), and the regular occurrence of poor water quality suggests that contaminant supply exceeds the capacity of the ecosystem to sufficiently remediate the pollutants introduced into it.

The coastal habitats (particularly the saltmarsh and sand dunes) also provide protection from flooding and erosion. There is some degree of manmade flood defence along almost the entire length of the estuary, and so the role of the ecosystem has probably been superseded by these interventions. However, a policy of managed realignment has been proposed for certain parts of the estuary, which would allow previously enclosed and defended areas to revert to intertidal zones (Environment Agency, 2008; Halcrow Group Ltd, 2009). The role of the ecosystem in flood and erosion control may therefore become more important.

Air quality and climate regulation are particularly difficult to quantify as a result of the wide range of other factors (which are not necessarily marine or local) that contribute to the supply of the benefit. The global scale of climate processes suggests that the estuary, in isolation, does not provide a significant benefit. There is no data on the non-use or option use values for the estuary.

Preliminary evaluation of the importance of the environmental benefits

The Taw Torridge itself is not a significant source of food or raw materials, although there is the potential for greater shellfish exploitation. Significant quantities of marine fish and shellfish caught in the open sea are landed at estuary ports, and the estuary will make some contribution to this fishery production. The estuary is used by marine fish (Environment Agency, unpublished data) and is a nursery for bass (Kelley, 1986), so there is the potential for developments within the Taw Torridge to have implications for the local inshore fisheries. However, the scale of the contribution by the Taw Torridge, and its relative importance compared to other local estuaries (such as Milford Haven, Burry Port and the wider Bristol Channel) is unknown.

The most significant benefit resulting from carrier services is the unique military facility for amphibious craft training. Cultural services provide much greater benefits, particularly given the importance of tourism to the area. The visual appeal of the unspoilt seascapes extending from the estuary mouth has been recognised by their designation as an Area of Outstanding Natural Beauty.

Water quality and flood risk are of significant concern, making it important to at least maintain, and ideally enhance, the delivery of regulating services. The management of waste entering the Taw Torridge is a serious issue, affecting both shellfish and bathing water quality. Two large mussel beds are rated Class C, which requires the mussels to be relayed at an approved site for at least two months prior to depuration (Food Standards Agency, 2010) and makes exploitation uneconomic. Bathing water at Instow was given an overall rating of ‘Poor’ for 15 summer seasons between 1990 and 2010 (Environment Agency, 2010). Concerns also exist about the potential breaching of historic landfill and industrial waste sites (TTEP, 1998). The Taw has been designated a Sensitive Area (Eutrophic) since 1998 under the Urban Waste Water Treatment Directive (DEFRA, 2008) and is also a Nitrate Vulnerable Zone under the Nitrates Directive (DEFRA, 2010a).

There is a significant flood risk to settlements surrounding the Taw Torridge estuary, many of which have substantial areas classified within the highest risk category (Zone 3 in the Government’s Planning Policy Statement 25) (Environment Agency, 2011). Nearly 2,000 properties are at risk in Barnstaple, 800 in Bideford and 500 in Braunton (Environment Agency, 2009). Floods also affect infrastructure including schools, hospitals, roads, railways, and electricity substations, although no sewage or water treatment plants are thought to be at risk (Environment Agency, 2009a). The most recent severe flooding event occurred in December 2012.

Quantifying changes in benefit delivery as a result of the proposed development

The construction of a tidal barrage is likely to affect a broad suite of benefits (as summarised in Figure 10, and see Chapter 1 for a full discussion). Quantification of the magnitude of the changes due to the barrage development was beyond the scope of this assessment. Instead, a simple assessment of the likely significance of the impacts has been made, identifying both the direction (positive, negative) and magnitude (high, moderate, slight) (Table 4).

Food benefits will potentially decline due to the risk of mortality of fish passing the barrage. Migratory species such as salmon and eels are likely to be most affected, although there may also be impacts on marine fish. An associated decrease in opportunities for recreational angling could also be expected. A decline in shellfish exploitation is likely if water quality deteriorates as a result of reduced flushing, and recreational watersports users may also be affected if contaminant levels increase. Conversely, there is the potential for watersports opportunities to increase as a result of higher water levels in areas upstream of a barrage, although this benefit could be tempered by the need for users to navigate the barrage when moving between different parts of the estuary.

The changes in water levels could also bring benefits to those enjoying the view of the estuary, as individuals may prefer to see water as opposed to mudflat, although the physical structure of the barrage itself may reduce the aesthetic appeal of the estuary. Noise levels in the proximity of the barrage will also increase. A barrage may also negatively affect wellbeing and opportunities for nature watching through the loss of intertidal area and the subsequent effects on, in particular, wildfowl and waders. The reduction in mudflat area is likely to be one of the most significant impacts of a tidal barrage, but substantial benefits could accrue in other areas. In particular, a barrage presents a significant research and education opportunity, and valuable flood protection could be provided for buildings and infrastructure upstream.

Table 4. A summary of the results of the Environmental Benefits Assessment, including confidence in the data presented and the potential scale of barrage impacts
Level of importance (in terms of policy drivers and/or number of people affected)**:** *** high, ** moderate, * low
Potential welfare impacts *Negative:* – – – high, – – moderate, – slight; *No impact:* 0; *Positive:* + slight, + + moderate + + + high

Environmental Benefit	**Importance**	**Measures (types and units)**	**Level of delivery in the Taw Torridge estuary**	**References**	**Confidence assessment**	**Potential Impact**	**Monetary valuation methods**
A. Direct use (consumptive)							
Food							
Shellfish – shore-based harvesting	*	Landing/harvest statistics (kg/yr)	Approx 180 tonnes of mussels per season	*pers comm.*(harvesters)	Moderate	– – –	Market price
Shellfish – subtidal	**		Unquantified. Little harvesting within the estuary, but important beyond the estuary mouth		Poor	–	
Eels	*		130-200kg of elver per year	DEFRA, 2010b	Moderate	– – –	
Salmonids	*		423 salmon and 889 sea trout per year	Environment Agency, 2009b	Moderate	– – –	
Marine fish	**		Unquantified. Small-scale commercial drift netters and recreational fishers exploit the estuary. 26 fishing boats, operating beyond the mouth, are licensed to estuary ports		Poor	– –	
Marine plants	*		Unquantified, small scale		Poor	0	
Raw materials							
Bait	*	Harvest statistics (kg/yr)	Unquantified, common		Poor	– – –	Market price
B. Direct use (non- consumptive)							
Provision of space							
Commercial transport	*	Frequency of ship passage	Approx. 7 arrivals per month on average	Bideford Harbour Master, unpublished data; Torridge District Council, 2010	Good	0	Market price
Moorings	*	Number of moorings	Unknown		Poor	–	Market price
Military operations	***	Frequency of exercises	Frequent usage (e.g. 1-2 trips/ week for larger Landing Craft Utility vessel, beach driving courses twice/ month)	*pers comm.*(Royal Marines)	Good	– –	Replacement cost
Cables and pipelines	*	Number of pipes/cables	At least one sewage pipeline, but no cables, cross the estuary	*pers comm.*(utility companies)	Moderate	0	Replacement cost

Environmental Benefit	Importance	Measures (types and units)	Level of delivery in the Taw Torridge estuary	References	Confidence assessment	Potential Impact	Monetary valuation methods
Recreation & tourism							
Sea angling	***	Number of participants	4 clubs, 550 members	*pers comm.*(recreation clubs) Abell and Bromham, 2009.	Poor	– – –	Travel cost, Stated preference
Wildfowling	*		1 club, 75 members		Poor	– – –	
Watersports	***		8 clubs, 880 members 149,000 visitors attracted, at least in part, by watersports		Poor	+ + +[1] / – –[2]	
Nature watching	***		Unknown		Poor	– – –	
Swimming	**		Unknown		Poor	– –	
Coastal margin activities	***		Unknown		Poor	–	
Cognitive development							
Education	**	Number of participants	Potentially 5,000+ child-visits per year	survey of local schools	Moderate	+ +	Travel cost, Stated preference
Research	*	Number of published papers/reports	83 papers/reports published	National Marine Biological Library (NMBL) database	Moderate	+ + +	Market price
Heritage & identity							
Archaeology	**	Number and importance of sites	Two scheduled ancient monuments and fish weirs within the estuary. Also shipwrecks at the mouth, lime kilns and World War II artefacts on the shore.	Preece (2005, 2008)	Good	– – –	Market price, Stated preference
Cultural heritage	***	Value to the community	Strong history of shipbuilding, fishing and maritime trade, which has recently been recorded in oral histories, and features in tourism media	Preece, 2008; Farr, 1976; Rogers, 1947	Poor	0	Stated preference
Psychological wellbeing							
Ambience (visual amenity, tranquillity)	***	Designations recognising natural beauty Value to the community	The area around the mouth of the estuary is within an Area of Outstanding Natural Beauty	North Devon AONB Partnership, 2009	Poor	++[3] / – – –[4]	Stated preference Hedonic pricing
Inspiration	*	Number/ frequency/ importance of art works	Prose, poetry, visual and performing arts have all been inspired by the estuary	Appledore Arts, 2010	Poor	+[5] / –[6]	Market price, Stated preference

Environmental Benefit	Importance	Measures (types and units)	Level of delivery in the Taw Torridge estuary	References	Confidence assessment	Potential Impact	Monetary valuation methods
C. Indirect use							
Contaminant control							
Water quality regulation	***	Frequency and severity of contaminant incidents compared to threshold	High levels of *E. coli* result in the regular downgrading of shellfish beds. 75% of bathing water quality ratings were poor between 1990 and 2010.	UK National Reference **Laboratory**, unpublished data; Environment Agency, 2010	Good	– – –	Avoidance cost, Replacement cost
Air quality regulation	*		Unknown		Poor	0	
Disturbance prevention							
Flood control	***	Number of properties flooded and frequency of events compared to threshold	There is some degree of manmade flood defence along almost the entire length of the estuary, and so the role of the ecosystem has probably been superseded.	NDC & TDC. 2009a,b; TTEP, 1998	Good	+ + +[7] / –[8]	Avoidance cost, Replacement cost
Erosion control	*	Area of land lost compared to threshold			Good	+[9] / –[10]	
Climate/weather regulation	*	Incidents of extreme weather compared to threshold	Unknown		Poor	0	
D. Additional components of total economic value							
Existence value Bequest value Option value	**	Value to the community	Unknown		Poor	–	Stated preference

[1] Increasing water level upstream providing longer access
[2] Barrier to navigation
[3] Higher water level increasing view of water (rather than mud)
[4] Presence of the barrage structure
[5] New structures and seascapes
[6] Changes to existing seascapes and noise
[7] Controls on tidal and fluvial flooding
[8] Potential groundwater flooding
[9] Reduced upstream erosion
[10] Increased erosion in the proximity of the barrage

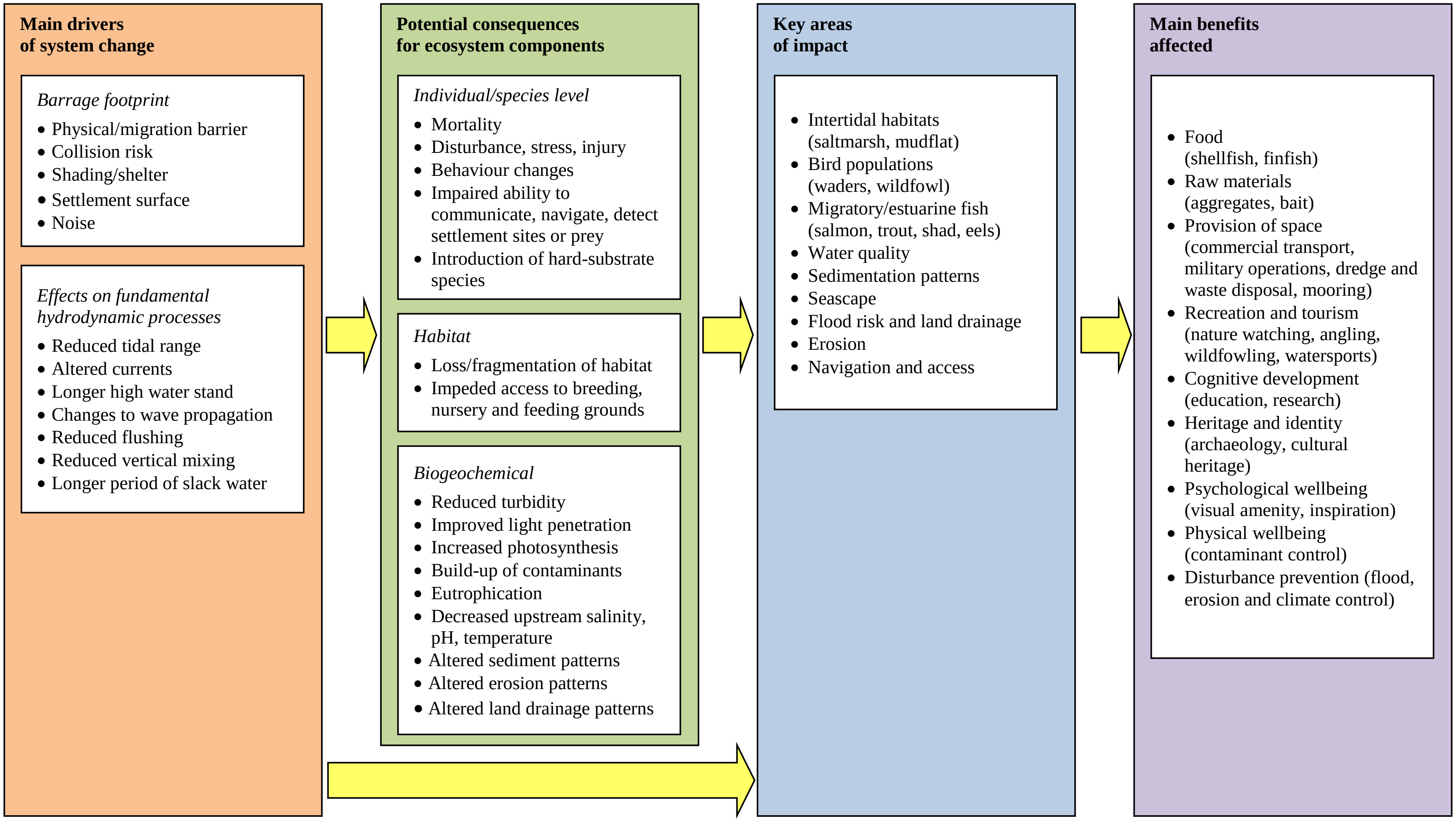

Figure 10. A summary of the significant environmental impacts likely to arise from barrage construction and the environmental benefits these will affect

3.6 Discussion

The framework for compiling an inventory of environmental benefits (Table 2) attempts to facilitate any ultimate valuation, but its purpose remains the coherent classification of benefits, not the resolution of all potential issues that may arise at the valuation stage. One such issue is the valuation of multiple benefits that are provided by the same service. For example, a fish provides food but angling also brings recreational benefits, or there may be emotional and identity benefits associated with commercial fishing if this continues a cultural tradition. Similarly, it may be difficult to disentangle the recreational and psychological benefits associated with regular walks along a coastal footpath. However, it is acceptable to assess (and ultimately value) these divergent benefits separately, providing they are distinct (Fisher and Turner, 2008), and so the comprehensive classification suggested in the framework achieves its purpose of facilitating valuation.

The empirical EBA carried out for a hypothetical tidal barrage in the Taw Torridge demonstrated that the proposed methodology can be successfully employed as a tool for evaluating the changes likely to result from local scale developments. There are, however, some limitations to its application, both in this specific case and more generally. In the case study, there are several gaps in the data, and poor confidence in the accuracy of much of the data that was available. This is partly as a result of the primarily desk-based nature of the case study: further empirical research would provide additional data. If an EBA is to be comprehensive and accurate, it will be necessary to identify all groups of beneficiaries and obtain information that is sufficiently representative of their activities. This will remain problematic where there are many small-scale users whose activities are not routinely recorded: comprehensive surveys will be required for, for example, recreational users and small-scale fishers. The likely variation in data accuracy (even where comprehensive empirical assessment is possible) illustrates the importance of presenting a confidence assessment with the data, so that it can be appropriately weighted during the decision-making process.

Limitations of the methodology

Quantifying cultural benefits

There are more systemic issues with the methodology, particularly concerning quantification of some of the cultural benefits. The Taw Torridge estuary is a source of inspiration, which has been demonstrated by, for example, local visual art works and events. The estuary also inspired Henry Williamson's classic novel *Tarka the Otter*. However, there is no obvious means by which to quantify inspiration in the same way as, for example, fish catches or number of recreational users: it would be impossible to track down all artworks that have been inspired by the estuary, and no way to document the less tangible results of inspiration that are integral to people's daily lives but produce no discernible outputs. Even where there is well known work, such as Williamson's novel, for which it would be relatively straightforward to quantify print runs and sales, it is not clear how to apportion these measures to the inspiration provided by the estuary and to other factors involved in the production of the book. Quantifying the likely change in inspiration as a result of an intervention would also be problematic. Even a development as substantial as a tidal barrage is unlikely to destroy the character of the entire estuary, and the development itself may provide a new source of inspiration. The ambience (including the visual amenity and tranquillity) of an area is similarly difficult to define and quantify, as is cultural heritage, especially in locations such as the Taw Torridge where the traditional industries or activities on which this heritage is based no longer occur and so will not be directly impacted by any modern development.

Inspiration, ambience and cultural heritage remain important components of the large and diverse range of benefits provided by the natural environment. Objective quantification of the level of delivery of these benefits is problematic, but there are appropriate (often narrative-based) methods within other social science disciplines to capture the strength and foundation of cultural values. Conceptual frameworks for ecosystem service assessments already acknowledge the difficulties in making quantitative assessments of cultural benefits, and also that simply recognising that cultural value exist may be sufficient to generate policy responses (TEEB, 2010; Daniel et al., 2012). Where they cannot be effectively quantified, cultural benefits should therefore be detailed within a qualitative section supporting the quantitative EBA, to ensure that any potential impacts upon them are considered and, where necessary, mitigated.

However, at the core of the ecosystem services approach is the intention to improve quantification of the benefits people receive from nature so that social and environmental externalities can be better compared with manmade capital. Reporting cultural services in only qualitative terms brings the risk that they will be overlooked, and so it is important that efforts continue to identify appropriate indicators and metrics for cultural services.

Aggregated benefits and cumulative effects

Application of the EBA also revealed a second major issue: attributing aggregate benefits to a local source. With shellfish harvesting, the ecosystem service (e.g. a mussel bed) is provided within the estuary, and the benefit is realised there, so the quantification of benefit delivery and potential impact from the development is relatively straightforward. The situation is more complicated for capture fisheries. Landings at ports within the estuary are recorded, but these do not all originate from the local area, and even where they do the direct role of the estuary in fisheries production is difficult to readily quantify. Modelling and production function approaches are required to quantify the fishery benefits delivered by the estuary and the effects on them of any proposed development (Jordan et al., 2012).

Scale is also an issue when considering the benefits from regulating services. The role of the local environment (in isolation) in providing these benefits is often negligible, and so the impact of a local-scale development may be effectively nil. This is particularly relevant to climate and weather regulation, as it seems highly unlikely that a development on the scale of a tidal barrage in the Taw Torridge will have any discernible effect on local weather patterns. However, the effects of local developments accrue cumulatively at a national level and account must be taken of this. This can be achieved by considering the service underlying the benefit (in this case carbon sequestration) which can be quantified at a local scale. The relative impact of a particular development, and its contribution to the cumulative impacts of other interventions can therefore be determined.

Restricting the focus to endpoints

For the purposes of valuation it is justifiable, indeed desirable, to focus on the endpoints of the ecosystem service cascade (Fisher et al., 2008; Boyd and Banzhaf, 2007; Wallace, 2007). However, failure to consider the underlying ecological processes restricts the application of an Environmental Benefits Assessment as a broader resource management tool. In management, attempts are made to maintain or modify the delivery of a benefit and so it is important to understand the implications of interventions at any stage in the benefit supply chain. Also, by the time changes in the ecosystem are manifested as changes in environmental benefits it may be too late to mediate the impacts that have negatively affected processes at lower levels in the system.

Water quality is one example of the need to understand the level of service delivery in addition to the benefit. The benefit of clean bathing or shellfish water is provided if contaminants are below a certain threshold. However, failure to also monitor the habitats responsible for pollutant sequestration could result in a sudden and unexpected decline in water quality, even where there has been no increase in contaminant input.

The EBA methodology as presented does not preclude its expansion to include consideration of the underlying services that are required to maintain the benefits. There is currently much interest in the development of indicators for marine ecosystem services (e.g. Samhouri et al., 2011; de Reynier et al., 2010; de Jonge et al., 2012) and these protocols could be incorporated into an EBA.

3.7 Summary

An Environmental Benefits Assessment (EBA) methodology is proposed that provides a systematic approach to evaluating the impacts of local-scale developments on environmental benefits. The case study of a hypothetical tidal barrage within the Taw Torridge estuary illustrates that the proposed Environmental Benefits Assessment (EBA) methodology functions well as a tool for evaluating the impacts of local scale developments, suggesting that closer association of ecosystem services approaches and EIAs would be possible in practice. However, the methodology is not without limitations, particularly the challenges associated with attempting to objectively quantify the delivery of cultural benefits and issues of scale. The proposed focus on benefits (as the endpoints of the ecosystem service cascade) restricts its application as a broader management tool as it excludes information that is highly relevant to managing resources in order to ensure the continued delivery of benefits. Extension of the methodology to include indicators for the marine ecosystem services that provide the environmental benefits remains possible.

The additional step of monetary valuation can provide a common metric for all the benefits assessed, facilitating comparison of the magnitude of impacts. In the following chapter, the theory of, and potential methods, for valuing the changes in environmental benefits will be discussed, as a precursor to the empirical valuation of estuarine mudflats that will be described in later chapters. Loss of intertidal habitats is a particularly significant impact of tidal barrages, making this habitat a pertinent focus for an empirical valuation study. The EBA highlighted the scarcity of existing local-level information for the Taw Torridge estuary, and this is a reflection of a wider absence of information on the value of mudflats, as the review of literature in the following chapter will demonstrate.

4 Valuation of Environmental Benefits at a Local Scale

4.1 Introduction

A tidal barrage has the potential to significantly impact on the environmental attributes of an estuary, with associated implications for society. The loss of mudflats (and the implications for bird populations), flood protection, deteriorating water quality, and changes to cultural benefits are areas of particular importance (as described in Chapter 2). The Environmental Benefits Assessment (Chapter 3) illustrated the lack of quantified information for cultural benefits in general, and non-use values in particular, for the Taw Torridge estuary. This reflects a general lack of empirical valuation data for UK estuarine mudflats.

This chapter reviews the literature to determine how changes in environmental benefits as a result of tidal barrage construction could be valued, discussing the use of, and opposition to, monetary valuation, and presenting an overview of the underlying economic theory. The review introduces the different methods for valuing environmental goods, focusing in more detail on stated preference techniques as these are the only methods that allow non-use values can be discovered. The chapter concludes with a discussion of contingent valuation and choice experiments, as these methods will be used in the empirical valuation. It also introduces the Analytic Hierarchy Process, a multi-criteria assessment technique, which will be used in the study to provide additional quantitative information to support the monetary valuation.

4.2 Monetary valuation of environmental benefits

Ecosystem goods and services challenge neoclassical economic theory because they involve significant non-market values and often cannot be assigned property rights (Straton, 2006). The lack of private property rights prevents a market from becoming established, as commodities cannot be bought and sold without owners (Common and Stagl, 2005). There may also be externalities associated with traded goods and services if their price does not reflect the costs to the environment, and the associated effects on third parties. A polluter's profits, for example, are not affected by the impacts of his activity on others, and the value of a fish to a trawlerman does not take account of the implications for other fishermen (current and future) or to society at large (Lipsey, 1989). Nor are Governments necessarily better at pricing resources, as subsidies distort the wider economy and can encourage activity that further degrades natural capital (Markandya et al, 2002). Governments, and individuals, also tend to short-termism, while society as a whole operates in a longer time frame.

Market and institutional failures have therefore led to natural resources being seen, historically, as unlimited “free gifts”, reducing the need for their conservation or sustainable exploitation. As natural capital continues to decline, this approach is no longer sustainable, and it becomes ever more important to understand how to value ecosystems (Daily et al, 2000).

Economic valuation of natural resources seeks to better quantify the social costs of ecosystem goods and services and can be particularly useful if markets and common property regimes have failed to effectively reflect the social costs of environmental degradation (Howarth and Farber, 2002). A further objective of economic valuation is to provide a common metric to allow the disparate services within an ecosystem, and also the market- and non-market-based values, to be better compared when evaluating costs and benefits.

Monetary valuation of environmental goods may be undertaken for a number of reasons, including attempts to determine a ‘snapshot’ of the total economic value at a given time, which may be used to highlight the relative value of different ecosystem types or different locations (Costanza et al. 1997; Martínez et al., 2007). Such snapshots could also be used to determine ‘green GDP’, so that natural assets can be reported in the same framework as market goods and services (Boyd and Banzhaf, 2007). Another use for valuation is in assessment of the costs and benefits of a specific project or policy intervention (Carpenter et al 2009; Fisher et al. 2009), which may involve consideration of the losses resulting from damage to a healthy ecosystem, or the costs to restore a degraded area (Turner et al., 2003). Valuation is also used to support the development of economic instruments such as habitat banking or payment for ecosystem services (PES) schemes (Ring et al, 2010; Fisher et al., 2009), or to determine the levels of compensation payable following oil spills or other accidents or incidents resulting in ecosystem damage (Dunford et al., 2004). Taxes on pollution or subsidies for better environmental practice have also been used in the development of environmental policy. The rate of ‘polluter pays’ taxation rarely has any direct link to the environmental costs (Palm and Larsson, 2007), and so valuation may also be useful in improving these economic instruments.

Using economic metrics to value environmental benefits attracts controversy, with opponents questioning the entire underlying philosophy of placing a monetary value on a natural resource, and also criticising the techniques involved, particularly those employing contingent valuation and discounting (see Ackermann and Heinzerling, 2004, for an overview). However, a purely moral approach is of no assistance when attempting to judge the merits of conflicting arguments, which may, morally, have equal weight (Costanza et al, 1997). Also, ecosystem valuation is not about trying to place an absolute “dollar value” on facets of the environment, but instead seeks to evaluate how the change in ecosystem service provision is traded off against other things people value (Turner et al., 2003). Valuation is not a stand-alone solution, it is a tool for organising information to help guide decisions (Daily et al, 2000).

Valuing environmental benefits may be gathering momentum, but the approach is not new. Environmental values have been used to inform project decisions for more than 40years, including for the construction of hydroelectric dams on Hells Canyon in USA in the late 1960s (Hanley, 1995). Ecosystem valuation been shown to confirm the importance people place on their environment, and that their willingness to pay for conservation can vastly outweighs the costs involved (Howarth and Farber, 2002). The process of deriving quantitative measures of value is not straightforward, but even an imperfect expression of value can help to inform the decision-making process (Daily, 1997). The growing acceptance of environmental valuation as a policy tool and its important role in informing management strategies was highlighted by the Millennium Ecosystem Assessment (2003), and later in The Economics of Ecosystems and Biodiversity (TEEB, 2010) and the UK National Ecosystem Assessment (2011).

4.3 Underlying economic theory

There are two approaches to the economic valuation of non-market goods: demand-side valuation is based on the concept that value originates with individuals and is measured through its marginal value or price, while supply-side valuation considers cost-of-production and assumes that value originates in the things from which goods and services are made (Straton, 2006). Cost-of-production approaches tend to focus on the flows of matter and energy required to produce an environmental good (Patterson, 1998).

On the demand-side, the premise underlying non-market valuation is that a person may be willing to pay money to secure an environmental improvement, if this exchange of income for the environmental good leaves her indifferent (Hanley et al., 1997; Markandya et al., 2002). Money is used as a measure of value: it represents what the person could have purchased instead of paying to secure the improvement in question (Farber et al., 2002). A measure of monetary value can also be obtained by considering what the person would be willing to accept as compensation for forgoing a benefit or enduring a loss of the non-market good (Markandya et al., 2002).

Public policies seek to improve an outcome. In welfare economics, a policy is judged according to the Pareto criterion: whether it makes at least one person better off while making no-one worse off. In practice, Pareto efficiency is seldom obtained unless those benefiting from the policy compensate those who are negatively affected, and such compensation is rarely paid (Mitchell and Carson, 1989). This led to the development of the Kaldor-Hicks criterion, which requires only that beneficiaries could potentially, as opposed to actually, compensate those who would bear the costs (Farrow, 1998).

In economic theory, the individual is assumed to have consistent preferences over bundles of goods and services, and these preferences can be expressed in a utility function in which the highest level of utility is obtained from the most preferred consumption bundle (Hanley et al., 1997). Utility u is a function of the vector of public goods $\mathbf{q}$ (= q_1,..., q_n) and the vector of private goods $\mathbf{g}$ (= g_1,..., g_m), which are available at prices $\mathbf{c}$ (= c_1,..., c_m) and the consumption of which is constrained by the individual's income y (Haab and McConnell (2002). Following Haab and McConnell (2002), the indirect utility function $V(\mathbf{c}, \mathbf{q}, y)$ is given by:

$$V(\mathbf{c}, \mathbf{q}, y) = \max\{u(\mathbf{g}, \mathbf{q}) \mid \mathbf{c} \cdot \mathbf{g} \leq y\} \qquad (4.1)$$

Where a policy proposes an improvement in the public good q, an individual's utility would be increased (Hanley et al., 1997). Assuming that the individual has no right to this increase in utility, and so must forgo market goods in exchange for the improvement, his willingness to pay (WTP) to secure this improvement is defined as the compensating surplus, which is the maximum sum of money the individual is prepared to give up rather than do without the improvement (Mitchell and Carson, 1989). Alternatively, the assumption could be that the individual does have a right to this higher level of utility, in which case the equivalent surplus is used: the minimum sum of money that would generate an increase in utility equivalent to that realised from the improvement in the environmental amenity (Mitchell and Carson, 1989). The particular circumstances will dictate when each of these welfare measures should be used. For example, if water quality is below a mandatory standard, people have the right to improved utility and so the equivalent surplus should be used, but if the policy seeks further improvement beyond this baseline level then the compensating surplus becomes appropriate (Flores, 2003).

A further important concept in non-market valuation is that of marginal utility. Attempting to value the total loss of an essential environmental good such as water would be beyond the realm of economics, which instead confines itself to less extreme changes in the level of provision and considers marginal WTP: the value of an additional unit of the environmental good (Bateman, 2009). The law of diminishing returns is generally assumed for most goods: the more an individual already has of a good, the less he will value an additional unit of it (Hanley et al., 1997). The availability of substitute goods is one factor in determining marginal WTP: if the good can easily be obtained elsewhere then its value will be lower than if the proposed change provides a unique benefit (Bateman, 2009). Location has a second effect on WTP, as the further an individual is from the good, the lower his value for it (Bateman, 2009).

Marginal economic value does not always follow a continuous function. When an ecosystem is close to a critical threshold, a small change can have dramatic consequences for the ecosystem and can cause economic values to change substantially (Farber et al., 2002). For example, a decline in bathing water quality from excellent to good is unlikely to have a significant effect, but a similar order of magnitude change that takes water quality below a minimum safe standard will have implications for recreation and health. Issues surrounding the uncertainty and irreversibility of outcomes resulting from the loss of environmental goods also have a bearing on value. The effect of irreversibility reduces the expected benefits of a development due to the loss of future options, and the expected value of benefits is also lowered where there is uncertainty about future outcomes (Arrow and Fisher, 1974). Holding back from implementing irreversible policies can also generate a quasi-option value, where the subsequent learning process increases knowledge and reduces uncertainty (OECD, 2006).

4.4 Introducing methods for non-market monetary valuation

Markets provide a means of capturing value that works relatively well for private goods which are excludable and rival in consumption (Farber et al., 2002). Most environmental services, as public goods, do not fall into this category. Where there is no explicit market for valuing environmental benefits or where market prices do not adequately capture the social value then more indirect means of assessing value are required.

One approach is to use production function methods. These consider the value of ecosystem services in terms of their contribution to the production of a marketed good or service (Barbier, 2007). A change in the provision of the environmental attribute may influence both the quantity of the marketed good and the production costs, and the implicit price of the environmental input is therefore the change in profit that results from the change in the input level (Markandya et al., 2002). The approach has the advantage of highlighting the essential role of ecosystem functions in the supply of environmental benefits, but it requires a thorough understanding of ecological processes, and this knowledge is typically incomplete (Barbier, 2007).

Cost-based approaches are more straightforward to apply as they use existing costs or prices, although they too have disadvantages, particularly in that the costs do not necessarily equal the damages that would arise from environmental degradation or the benefits that would accrue from improvements (Markandya et al., 2002). Examples of cost-based approaches include replacement cost, which considers the cost of a manmade alternative to an ecosystem service such as waste-water treatment, and avoidance cost, which evaluates the extent to which the presence of the ecosystem service avoids the need for costly averting behaviours and mitigation (Lui et al., 2010).

Avoidance costs provide only the lower bound of value, especially where there is no adequate substitute for the ecosystem service (Daily et al., 2000)

A third major type of valuation method is revealed preference, which involves examining the prices people pay in real markets and relating these to the environmental commodity that influences preferences for the marketed good (Markandya et al., 2002). Hedonic pricing uses the price differential between two products that vary by a single environmental characteristic as a means of observing the monetary trade-offs individuals are prepared to make with respect to that characteristic (Taylor, 2003). Most environmental uses of hedonic pricing relate to house prices (Haab and McConnell, 2002). A second revealed preference technique that has been widely used is the travel cost method. As its name implies, the method considers the cost of travel to a site where the environmental good is provided (and also the frequency of trips) as an expression of the value places on this good, and is commonly utilised in valuing recreational uses of the environment (Parsons, 2003).

Revealed preference techniques are attractive because they are based on actual behaviour, but, as with the other valuation methods, they have drawbacks. Problems in determining the opportunity cost of travel time, the treatment of substitute sites and visits with multiple purposes have not yet been adequately resolved for the travel cost method (Markandya et al., 2002; Martinez-Espineira and Amoako-Tuffour, 2009). Also, revealed preference methods can only measure use values. Determining non-use values requires stated preference techniques.

Stated preference methods involve directly asking respondents how much they would be willing to pay to increase the level of an environmental good, or how much they would be willing to accept in compensation if the level of the good were to decline. Obtaining this willingness to pay (WTP) or willingness to accept (WTA) requires careful construction of a hypothetical market; the drivers of the environmental change, its extent, timing and implications, the method by which payment would be collected and the timeframe for payment must all be described to respondents in a credible scenario (Boyle, 2003; Bishop et al., 1997). Care is also required because stated preference surveys may return biased values if the survey structure, wording or pool of respondents encourages a particular response (Adamowicz, 1995).

4.5 Stated preference techniques

The established frameworks for evaluating ecosystem services recognise the importance of the psychological benefits provided by the environment (see Chapter 3 for a review). These benefits may arise even if an individual makes no use of the environmental good in question, as in the case of the wellbeing derived from knowing that a particular species or habitat exists (existence value) or that it will remain available for future generations (bequest value). There may also be value to an individual in retaining the option to use the good in the future (option value), even if he does not use it at present. The metrics by which to derive non-use values are limited, as these benefits are generally not marketed or otherwise captured by revealed preferences. This leaves stated preference as the only method by which to quantify non-use values (Flores, 2003).

This study focuses on estuarine mudflats, as their loss is one of the most significant environmental impacts likely to arise from barrage construction, but there is a lack of empirical studies that attempt to value the habitat. Direct uses of mudflats are limited and so it is expected that the values expressed by the general public for the habitat will include a non-use component (particularly for those who do not live close to the estuary in question), requiring the use of stated preference techniques.

The use of stated preference techniques is not without criticism, including questions as to whether it is even valid to attempt to include existence values in economic assessments (Rosenthal and Nelson, 1992). However, non-use values contribute to individual wellbeing, and so are relevant to economic efficiency, although the issue of pure altruism within non-use values remains problematic (Freeman, 2003). Also, the failure to evaluate non-use values may result in substantial underestimation of willingness to pay (Carson et al., 2001), and hence the continued undervaluing of natural resources. It is important to assign monetary values to as many categories of economic value as possible in order to provide policy makers with appropriate information on which to base development decisions (Markandya et al., 2002).

Economic theory suggests that WTP should increase as the quantity of the environmental good increases (Carson et al., 2001). The apparent failure of some stated preference studies to show this sensitivity to scope has led some authors to assert that WTP does not represent a monetary value for the good in question, but is instead the value of the moral satisfaction obtained by the respondent in contributing to a good cause (Kahneman and Knetsch, 1992). However, a lack of scope sensitivity may also be a reflection of the difficulties faced by respondents in valuing changes where these represent a small proportion of the total quantity of the environmental good, even where the absolute change varies by an order of magnitude (Boyle et al., 1994).

Further criticism of stated preference techniques has arisen because hypothetical bias has been demonstrated: a respondent may over- or understate WTP because he is not faced with an actual cost (Perrings, 1995). Stated preference techniques may also elicit higher WTP values compared to revealed preferences for the same goods. Meta-analyses vary in their derived magnitude of this overstatement, suggesting, for example, that it is typically by a factor of 1.35 (Murphy et al., 2005) or about 3 (List and Gallet, 2001), both of which imply that values obtained by stated preference are reliable at least in their order of magnitude. Comparisons between revealed and stated preferences have used within- and between-sample designs, and the former is appealing because using the same subjects reduces variation by controlling for individual effects (Mitani and Flores, 2009). The discrepancy between hypothetical and revealed preferences is generally smaller in within-sample tests (Murphy et al, 2005; Johansson-Stenman and Svedsater, 2007), although this may indicate only that the respondents feel obliged to show consistency (Krawczyk, 2012).

Examples of within-sample tests that further investigate hypothetical bias have included following up a hypothetical valuation scenario by providing respondents with an opportunity to make an actual payment. In some cases, there was no significant difference at the population level between the hypothetical and actual WTP (Carlsson and Martinson, 2001; Camacho-Cuena et al., 2004), although there were discrepancies at the individual level, particularly for respondents at the tails of the distribution (Camacho-Cuena et al., 2004).

Other studies confirm that the average WTP is higher in the hypothetical scenario than in the actual follow-up payment (Krawczyk, 2012; Christie, 2007; Alpizar et al, 2008). However, investigation at the individual level has shown that those respondents who do actually contribute give an amount that closely matches their stated WTP (Christie, 2007; Duffield and Patterson, 1991, cited in Arrow et al., 1993). This suggests that the issue is not necessarily with all individuals overstating their WTP in a hypothetical scenario, but with some respondents providing a positive WTP when in fact they have no real intention to contribute at all.

The validity of stated preference has also been criticised because WTP has been shown to vary across different elicitation methods (Champ and Bishop, 2006; Cameron et al., 2002), but theories to explain the psychology of WTP responses, and hence the variation with elicitation format, have evolved (Carson and Groves, 2007; DeShazo and Fermo, 2002). Furthermore, proponents of stated preference argue that many of the criticisms relate to poor application of the method or to the choice of inappropriate validity criteria, and so do not invalidate stated preference *per se* (Herberlain et al., 2005; Carson et al., 2001; Kopp, 1992). Improved data collection and analysis methods have been developed to address biases, such as the use of payment cards to reduce anchoring bias and yea-saying (Boyle, 2003).

There are two principal methods for eliciting the willingness to pay from respondents: contingent valuation, which provides an estimate of WTP for the good as a whole, and choice modelling, which can provide estimates for individual attributes of a particular good (Bateman et al., 2002).

Contingent Valuation

Contingent valuation (CV) has long been a popular technique for valuing non-market environmental goods (Carson et al., 2001). This is perhaps because CV is uniquely placed to ascertain how costs and benefits are distributed across the sample population, and this information is often more important to policy makers than aggregated values (Mitchell and Carson, 1989). Individual preferences are important in driving policy: for example, public consultation is a prerequisite of planning decisions, and a stakeholder-driven, bottom-up process was used to determine the proposed national network of Marine Conservation Zones (Natural England and JNCC, 2010).

In contingent valuation, the respondent is asked to consider a change in the quantity of a public good and then to state what corresponding change in his income would leave his utility level unaffected (Mitchell and Carson, 1989). This change in income can be expressed in terms of the amount he would be willing to pay to secure an increase in the level of the good, or the amount of compensation he would be willing to accept if the level of the good were to decline. The latter approach is less commonly applied in environmental valuation: WTP and WTA can vary widely for the same economic good (Hanemann, 1991), and the acceptance of WTP as the standard method was influenced by the NOAA Blue Ribbon panel recommendation on the use of WTP, as the more conservative estimate (Arrow et al., 1993).

As described in Section 4.3 above, the respondent's utility function depends on his income, the status of the environmental good, and his other outgoings (the prices of the private goods he chooses to consume). The respondent's utility derived from the status of the environmental good will be influenced by any use he makes of the environmental good (D) and any non-use values he holds for it (NU), and his WTP may also be influenced by other psychological factors that may motivate him to contribute (M) (Bateman et al., 2005). The valuation function (v_j) for the *j*th good can therefore be expressed as:

$$WTP = v_j(D, NU, M) \tag{4.2}$$

In empirically assessing the WTP for a particular environmental good, researchers generally seek to define it in terms of the social, economic, and attitudinal factors that are significant influences on the stated value. Thus, the researcher derives a model to express the relationship between WTP and the explanatory variables representing such factors (x_1-x_k), which are weighted according to the parameters, β_1- β_k, Assuming the association is linear, the relationship between WTP and the explanatory variables can be expressed as:

$$WTP = \alpha + \beta_1 x_1 + \dots + \beta_k x_k + \varepsilon \tag{4.3}$$

where α is a constant term representing WTP in the absence of the measured variables, and ε the disturbance term, which accounts for the factors influencing WTP that cannot be measured by the researcher (after Dougherty, 2011).

A range of formats have been used to elicit WTP through contingent valuation, including open-ended questions, bidding games, and dichotomous choice. With open-ended formats, the respondent is asked to state his maximum WTP to secure the improvement. Drawbacks with this technique include the possibility for strategic behaviour (with the respondents stating a value he thinks will influence the policy to his advantage as opposed to his true WTP) and also the lack of a reference point on which the respondent can base his value judgement (Markandya et al., 2002). There is a theoretical advantage to this latter issue, in that the lack of valuation cues prevents anchoring bias (Bateman et al., 2002). In practice, however, it tends to cause open-ended formats to return a high proportion of zero bids since respondents are unable to respond given the cognitive load (Desvousges et al., 1983, cited in Mitchell and Carson, 1989). Payment card approaches have evolved to address the lack of context, as they present a series of values that provide reference points for the respondent, although the range of values presented on the card can produce its own bias (Bateman et al., 2002).

In a bidding game, respondents are asked whether they are willing to pay a particular price, and if they accept (refuse) the amount is gradually increased (reduced) over several rounds and the process concludes with an open-ended WTP question (Markandya et al., 2002). A particular problem with bidding games, however, is starting point bias: the amount used for the initial bid can influence the respondent's stated WTP (Mitchell and Carson, 1989). The dichotomous choice format evolved to address both strategic and starting point biases (Markandya et al., 2002). In this "take-it-or-leave-it" approach, a respondent is asked a single question about whether they are willing to pay one specified amount (Mitchell and Carson, 1989). Dichotomous choice too has its disadvantages: WTP elicited using this format has been shown to be significantly and substantially larger than that obtained using open-ended questions, it is effected by both yea-saying and nay-saying, and is an inefficient means of collecting information requiring a large sample size and stronger statistical assumptions (Bateman et al., 2002).

Choice Experiments

An alternative approach to contingent valuation is the choice experiment, which has been growing in popularity. A search of the Web of Knowledge database shows that the number of published studies with "choice experiment" in the title has grown rapidly from less than 10 each year during the period 1991 to 2004, to 81 in 2012. A similar search for "contingent valuation", however, shows a jump in publications after 1992, followed by a fairly constant output of, on average, 35–40 papers per year.

The economic theory on which choice experiments are based is a refinement of that underlying contingent valuation. Choice experiments reflect Lancaster's (1966) theory that people consider the characteristics of goods (rather than the good as a whole) and spread their purchasing power to obtain efficient sources of the preffered mix of characteristics. Choice experiments present respondents with a set of alternatives, each of which is defined by a series of attributes (including cost) (Grafton et al., 2004). This mimics real market situations, in which people are faced with a choice of goods with similar attributes but different levels of those attributes (Alberini et al., 2007). This focus on trade-offs yields estimates of the marginal rate of substitution between pairs of attributes, and, where price is one of the attributes, the marginal WTP for the attribute can be derived (Freeman, 2003). Careful experimental design ensures that the attributes are uncorrelated, and so choice experiments yield unconfounded estimates of the parameters of the conditional indirect utility function (Grafton et al., 2004).

Following Hanley et al. (1998), the utility function for individual *a* takes the form:

$$U_{ia} = U(Z_{ia}, S_a) \qquad (4.4)$$

where utility depends on the attributes *Z* and the individual's socio-economic characteristics *S*. The utility function has both deterministic and unobservable components, so Equation 4.4 can be rewritten:

$$U_{ia} = V(Z_{ia}, S_a) + \varepsilon(Z_{ia}, S_a) \qquad (4.5)$$

The probability that alternative *i* will be chosen over other options *j* is given by:

$$\text{Prob}(i \mid \mathbf{O}) = \text{Prob}\{V_{ia} + \varepsilon_{ia} > V_{ja} + \varepsilon_{ja}, \text{all } j \in O\} \qquad (4.6)$$

where **O** is the complete choice set.

Choice experiments have some particular advantages over contingent valuation methods, not least that they do not explicitly ask "what are you willing to pay?", a question respondents may find challenging to answer (Bateman et al., 2002). Also, they elicit several responses from each respondent (Grafton et al., 2004) and so are more efficient that contingent valuation. Researchers have a unique opportunity to design their experiments (Kanninen, 2002) and this control yields greater statistical efficiency and eliminates collinearity (Grafton et al., 2004). By providing information on the component attributes of an environmental good, choice experiments provide a more completed characterisation of the utility function and so may have an improved potential for benefits transfer (DeShazo and Fermo, 2002). A further advantage is that the differences in attributes levels allow for issues of scope to be addressed internally within choice experiments (Grafton et al., 2004).

That is not to say that choice experiments are without drawbacks: they can place a cognitive burden on respondents as the choice sets are often large and complex (DeShazo and Fermo, 2002). The choice of which attributes to include is a particular issue, as the larger the list of attributes, the greater the complexity. However, it is important that the choice experiment capture those attributes that are most important for the majority of respondents to avoid omitted variable bias (Hoyos, 2010), which would lead to poor model specification and biased parameter estimates. Questions also arise around the appropriate range of attribute levels (Grafton et al., 2004). The vector of prices selected, for example, may (Luisetti et al., 2011) or may not (Hanley et al., 2005) have a significant effect on WTP.

Factors motivating WTP

Stated preference surveys allow motivations behind WTP to be assessed by collecting supporting information on the social and demographic characteristics of the respondents. Economic theory contains hypotheses on the expected relationships between certain of these characteristics and WTP. As well as considering the influence of characteristics such as income and gender, hypotheses have also been formed that concern proximity to, and familiarity with, the environmental good. It has been suggested that a lack of understanding of ecological systems inhibits our ability to place a monetary value on them (Fisher et al., 2009) and that responses to contingent valuation are only meaningful if the respondent is familiar with the good in question (Desvouges et al. 1993).

The theoretical expectations are that WTP will increase with increasing information or experience, and will decrease with increasing distance from the affected ecosystem, and these have been tested in multiple split samples assessments (e.g. Bergstom and Stoll, 1990; Blomquist and Whitehead, 1998; Cameron and Englin, 1997; Hanley et al, 2003). Testing the conformity of results to these theoretical expectations is a means of assessing the robustness of the WTP elicited in empirical research. Additional studies that examine these hypotheses can also improve understanding of the influence of proximity and familiarity on welfare estimates. This is important in determining how to aggregate benefits across the wider population, particularly as distance decay functions may not be transferable between different environmental goods (Hanley et al., 2003).

The Analytic Hierarchy Process

Economic valuation is just one means of providing information on people's preferences for environmental benefits and the trade-offs that they might make in order to secure them. Complementary methods can be used to validate results or improve understanding of the factors that influence WTP. The New Ecological Paradigm (Dunlap et al., 2000) is an example of a technique that has been used for the latter purpose. This means of assessment of environmental attitudes has been applied in conjunction with contingent valuation as a means of examining the motivation behind respondents' WTP for lake water quality improvement (Cooper et al., 2004).

The Analytic Hierarchy Process (AHP) is a quantitative method for evaluating the relative importance of the individual criteria that may be considered in a decision-making process. AHP was originally devised as a technique for a single decision maker to evaluate trade-offs (Duke and Aull-Hyde, 2002), but is now commonly used to assess the preferences of multiple individuals. Since the method was originally proposed (Saaty, 1980), citations in the Web of Knowledge database suggest that interest in the method has grown exponentially, with over 600 papers published on the topic in 2010. AHP has been the dominant multi-criteria decision analysis tool used in environmental science over the past decade (Huang et al., 2011) and has been applied in a variety of decision-making contexts including renewable energy policy (Shen et al., 2010), land-use planning (Ananda and Herath, 2008), and the impact of fishing gears (Innes and Pascoe, 2010). However, AHP has been rarely used as a tool for understanding economic values.

In an AHP assessment, survey respondents are asked to make pairwise comparisons of the attributes of interest, and to express on a scale of 1 to 9 the magnitude of their preference for one attribute over the other (Saaty, 1990; and see Table 5). Pairwise comparisons offer advantages over other ranking and rating methods as they can more precisely differentiate the relative importance of the various attributes and can provide the most accurate comparative weights (Mendoza and Prabhu, 2000).

Table 5. The scale used in making judgements in AHP (Saaty, 1990).

Intensity of importance on an absolute scale	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgement slightly favour one activity over another
5	Essential or strong importance	Experience and judgement strongly favour one activity over another
7	Very strong importance	An activity is strongly favoured and its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgements	When compromise is needed

AHP can be used to complement monetary valuation in a number of ways. It can offer a broader context to contingent valuation (which provides willingness to pay only for a single parameter) and also provide a means of comparison with a choice experiment, as both techniques generate information on the relative value of environmental attributes. AHP has also been combined with choice experiments and contingent valuation to expand the scope of economic studies, for example to provide a better understanding of water quality valuation results (Martin-Ortega and Berbel, 2010) and to explore preferences for individual attributes of multifunctional agricultural systems (Kallas et al., 2007).

Empirical application of stated preference surveys to marine ecosystems

In the context of the marine environment, Marine Protected Areas have been a particular focus of stated preference assessments (e.g. Stamieszkin et al., 2009; Svensson et al, 2008; Togridou et al., 2006), as have large marine vertebrates (Jones et al., 2011; Jin et al., 2010; Solomon et al., 2004) and coral reefs (Ransom and Mangi, 2010; Park et al., 2002). Stated preference methods have also been used in valuations of water quality (Machado and Mourato, 2002) and harmful algal blooms (Nunes and van den Bergh, 2004), amongst other marine environmental goods and services.

Wetlands in general have been the focus of a number of stated preference studies, both globally (e.g. Pattison et al., 2011; Petrolia and Kim, 2011; Birol et al., 2009; Brander et al., 2006), and in the UK (Luisetti et al., 2011; Birol and Cox, 2007), but these tend to use a broad-scale definition of wetland, which encompasses a range of terrestrial and marine habitats. More specific, habitat-level studies have included economic valuation of salt marshes (Bauer et al., 2004), but there appears to be a lack of published empirical valuations focussing specifically on estuarine mudflats. The need for more primary value data was explicitly emphasised in the recent economic valuation of the impact on ecosystem services from the shortlisted Severn tidal barrage options (Hime and Ozdemiroglu, 2010), which, in the absence of empirical data, was based entirely on the transfer of values from a global wetland meta-analysis.

4.6 Summary

Monetary valuation is a tool that allows a diverse range of parameters to be compared using a common metric, providing a framework for the assessment of relative preferences and trade-offs. There are several methods that can be applied, depending on the type of attribute to be valued. Little is known about how members of the public view estuarine mudflats, but any value is likely to contain a non-use component, and this can only be captured using stated preference techniques. These methods will therefore be used for the empirical components of this study.

Given the lack of previous work on preferences for mudflats, there is no precedent literature with which to compare the outcomes of this research. The criticisms of stated preference techniques generate concern that the application of contingent valuation alone may provide unreliable estimates of WTP. Therefore, the study will apply two different methods, contingent valuation and a choice experiment, in order to determine whether the value obtained is consistent between the techniques. The study will also explore the use of a multi-criteria technique, the Analytic Hierarchy Process, to support the empirical valuation. Using the AHP will provide information about levels of concern for the environmental good in question, and its relative importance compared to other barrage attributes. Distance decay and the influence of specialist knowledge on WTP will be assessed, to permit evaluation of the results in light of theoretical expectations.

The following chapter details the development of a credible hypothetical scenario which will form the basis of the stated preference survey instruments. The development of the survey instruments, and further details of the specific econometric models that will be used in the data analysis, are presented in Chapter 6.

5 Methods: Scenario Development and Focus Groups

5.1 Introduction

This chapter builds on the qualitative assessment of barrage impacts described in Chapter 3 by seeking to determine the expected changes in selected ecological, social and economic parameters and so create a robust hypothetical scenario for the valuation exercise. Different barrage locations, technologies and operating modes were considered, and a range of levels for twelve barrage attributes and impacts were determined.

A monetary value for estuarine mudflats remains the focus of the study (as empirical values have not yet been determined) but other parameters are also of interest as another purpose of the research is to determine trade-offs between environmental and social goods and services. Quantitative estimations were made for attributes including power generated, habitat impacted, and flood protection, supplemented by qualitative assessments of the likely impacts on visual amenity, water quality, fish and ship passage, and learning opportunity.

Public perceptions of tidal barrage impacts were also incorporated in the development of the scenarios, through the input of focus groups. These were necessary to the design of the survey instrument, in light of the lack of available literature on attitudes to either tidal barrages or estuarine mudflats. The focus groups were also used to determine the extent of knowledge amongst members of the public (and hence the type of supporting information that would be required within the survey instrument) and how they prioritised barrage advantages and disadvantages. Focus groups also provided an opportunity for scoping acceptable payment vehicles for the collection of barrage cost premiums, the range of those payments and acceptable levels of habitat loss.

5.2 Development of Plausible Scenarios

Different tidal schemes and their potential implications

The plausibility of the hypothetical scenario is very important in ensuring that a contingent valuation survey elicits meaningful and reliable responses from respondents (Mitchell and Carson, 1989). In order to develop this scenario, a detailed assessment of the possible implications of a tidal barrage in the Taw Torridge was undertaken, which considered different sites and barrage technologies. This builds on the generic assessment of likely impacts described in Chapter 3, and is again somewhat hampered by the lack of published quantified information for the Taw Torridge. No detailed feasibility study for a tidal barrage in the Taw Torridge has been undertaken, and the most comprehensive assessment remains that carried out by Binnie and Partners (1989) as part of a preliminary study of tidal range resources throughout the UK. An outline proposal for a barrage across the mouth of the estuary at Airy Point was submitted in 2008 (North Devon Gazette, 2008; Apps, 2010) but this provides very limited supporting information.

A scenario using an Airy Point barrage and so encompassing impacts on the Biosphere Reserve (Figure 11) could be a means of determining existence value, as the designation identifies the area as an important habitat and so could be used to engage non-users. However, it could be argued that the designation of the reserve has already ‘valued’ the area, and as such responses would relate to the value placed on a UNESCO site as opposed to the value for the estuary mouth itself. Also, it is unlikely that planning permission would be granted for a barrage expected to impact significantly on the Biosphere core zone, and there are issues of erosion around the estuary mouth. Therefore, there would be issues of credibility with any scenario based around an Airy Point barrage.

Consideration of plausible tidal energy scenarios for this study therefore focused instead on two sites within the Taw (Figure 11). The first is near Crow Point, which is located on the edge of Braunton Burrows, and so represents the largest area within the estuary (and therefore energy output) that can be used without direct impact on the biosphere core zone. The second proposed site is east of Isley Marsh, and so excludes the RSPB wetland bird reserve but also puts the river Caen seaward of the barrage, thus excluding the residents of Braunton from potential flood protection benefits.

Figure 11. The proposed tidal barrage sites, and the important estuary features excluded under the Isley scenario

Different methods for power generation were also considered, as these also cause variation in the attributes of a tidal power scheme. A traditional barrage configured in both two-way and ebb-only generation modes was considered, as were two new concepts that have been explored in detail under the Severn Embryonic Technologies Scheme (SETS): a tidal bar consisting of very low head, bi-directional turbines within a barrage, and a tidal fence option comprising an open row of tidal current turbines (DECC, 2010b). The SETS options remain at the concept stage, although the technology for the tidal fence has been proven through field trials of individual tidal current turbines that have been deployed at, for example, the European Marine Energy Centre. The tidal bar is entirely untested and so presents considerable risk that the energy output, environmental impact or cost may differ significantly from predictions. Other schemes to extract tidal energy are also possible, such as a tidal fence design incorporating a partial barrage to funnel the flow past tidal current turbines. However, such designs have not been assessed in detail and there is insufficient information within the literature to determine how such a scheme would compare with other operating modes in terms of its power output, environmental impacts and cost of energy.

The attributes of each barrage design (Table 6) were determined using figures in the literature for tidal barrages proposed for other estuaries. The figures generated from these broad assumptions are sufficiently plausible to allow reasonable comparison of the different scenarios for the purposes of this research. However, they cannot be considered as accurate estimates for the actual situation likely in the Taw because each estuary is unique so the transferability of results is limited, particularly as the Taw has an irregular tidal curve with a long low water stand near Barnstaple on spring tides. Accurate quantification of the power generated and the area of habitat impacted would require modelling, which is beyond the scope of this study. Constraints on technical feasibility are also not considered. In particular, the Taw is shallow at low tide, so any additional economic cost or environmental implications of, for example, dredging the barrage site, have not been factored into the scenarios employed here.

Energy

The annual energy produced by an ebb-only barrage was calculated using the equation derived by Prandle (2009), which states that energy, $E = 0.27(4\rho g A^2 S)$, where $g = 9.81 m/s^2$ and $\rho = 1025 kg/m^3$. A is the M2 constituent of the tidal range (the dominant harmonic constituent, representing the influence of the moon in creating two tides per day), and the published value for Appledore (Alcock and Pugh, 1980) was used for both barrage sites. S is the area of the basin enclosed by the barrage, which was calculated from Ordnance Survey maps to be $8.6 km^2$ for the Crow Point barrage and $6 km^2$ for the Isley site.

Two-way generation may be considered in a barrage design as it can reduce the environmental impacts. However, this mode is expected to produce 80% of the energy of an equivalent ebb-only barrage, due mainly to inefficiencies of bi-directional turbine operation (AEA, 2006). The relative output of a tidal fence and a tidal bar compared to an ebb-only barrage was determined from the ratio of energy produced by such schemes as proposed for the Aberthaw to Minehead option for a Severn barrage (Parsons Brinckerhoff, 2008a; Rolls Royce and Atkins, 2010), as this is the only instance where comparable assessment of multiple schemes has been made for the same site.

The total annual energy output is more accessible to members of the public where it is described in context and so was converted to the number of homes that could be powered using a figure of 4,481kWh as the average annual domestic electricity consumption in the South West (DECC, 2010e). The larger schemes could power up to 32,000 homes, and so could make a significant contribution to local domestic electricity demand as the population of Barnstaple is nearly 25,000 and Bideford 17,000 (Devon County Council, 2010). The total power output of each scheme was also assessed in terms of the greenhouse gas reduction achieved by substituting for grid electricity produced from fossil fuels, using a conversion factor of 0.542kgCO_2 per kWh (DEFRA, 2010c).

Table 6. The attributes of the different barrage operating modes at the Crow Point and Isley Marsh sites

	Barrage				**Other technology**		
Location	**Crow Point**		**Isley**		**Crow Point**		**Isley**
Scheme type	**Ebb-only**	**Two-way**	**Ebb-only**	**Two-way**	**Tidal Fence**	**Tidal bar**	**Tidal bar**
Power generated (GWh/yr)	120	95	80	66	16	142	98
Number of homes powered	26,500	21,000	18,500	14,500	3,500	32,000	22,000
Greenhouse gas reduction (tonnes/yr)	62,000	50,000	43,000	35,000	8,000	74,000	52,000
Area of saltmarsh & mudflat impacted (ha)	220	140	120	80	3	42	24
Number of homes protected from flooding	2,400	2,400	1,900	1,900	None	2,400	1,900
Visual impact	High	High	High	High	Low	High	High
Deterioration in water quality	High	Moderate	High	Moderate	Unchanged	Low	Low
Impact on migratory fish	High	High	High	High	Low	Moderate	Moderate
Restrictions on passage of ships	High	High	High	High	Low	Moderate	Moderate
Improvement in upstream watersports potential	High	Moderate	High	Moderate	None	Low	Low
Learning opportunity	Low	Low	Low	Low	Moderate	High	High
Additional annual premium on electricity bill (£)	Baseline	94	108	226	257	-104	-23

Habitat loss

Mudflat and saltmarsh are important intertidal habitats that would be impacted by a barrage development. The total area of these habitats upstream of the barrage sites was calculated as 490ha and 275ha affected by the Crow Point and Isley barrages respectively, using maps from the Devon Biodiversity Records Centre. It is unlikely that barrage operation would result in the complete loss of the total area of upstream habitat. The actual proportion of intertidal area lost under ebb and two-way generation in four large estuaries on the UK's west coast has been modelled (Wolf et al., 2009), and results from that study were used to calculate the area likely to be lost under each scenario in the Taw. The effect of a tidal fence on intertidal habitats is not thought to be significant, as the tidal regime will remain unchanged. For example, for a Severn tidal fence, it was estimated that less than 0.5% of the intertidal habitat would be lost (Godfrey and Griffiths, 2010), and in a Severn tidal bar scheme, the habitat loss was predicted to be about 19% of that under an ebb-only scheme (Parsons Brinckerhoff, 2008a; Rolls Royce and Atkins, 2010).

Flood defence

The North Devon Catchment Flood Management Plan (Environment Agency, 2009a) states that 1,900 properties in Barnstaple are at risk of flooding, with a further 500 in Braunton. Both towns (and other settlements on the estuary) have experienced floods of varying severity in the past, including the inundation of about 200 properties on the estuary in October 2000 (Environment Agency, 2008) and a further severe event in December 2012. The construction of flood defences has alleviated the frequency and severity of flood events, particularly in Barnstaple (NDC and TDC, 2009a), although areas lacking complete defences continue to flood. For example, Bishop's Tawton, at the tidal limit of the Taw, has flooded 15 times in the past 50 years (Environment Agency, 2008). Significant areas of the Caen (through Braunton), and the Taw are classified in the highest flood risk category according to the Government's Planning Policy Statement 25, and flood risk, and its economic impact, is expected to increase in the future (Environment Agency, 2008).

A barrage at Crow Point would provide flood defence for all properties upstream on the Taw, while the Isley barrage would exclude Braunton as the Caen would be downstream of the site. Past flooding has been a combination of fluvial, tidal and surface water inundation (Environment Agency, 2008). Barrages can protect against tidal flooding through closure of the sluice gates to prevent the tide entering the basin and construction of the dam wall of a sufficient height to prevent overtopping by storm surges. Restricting entry by the tide into upstream areas provides protection from fluvial and surface water flooding, as it provides a larger basin into which rivers and drains can discharge.

Visual impact and water quality

The different operating modes also have varying impacts on other environmental parameters. A large, concrete tidal barrage will have a much larger visual impact than a tidal fence scheme as the surface area of the former structure is much larger (Figure 12). Water quality will also be affected as the barrage will reduce flushing allowing nutrients and pollutants to build up behind the barrage. Two-way operation retains a more natural tidal regime, so the implications for water quality (and dependent services such as shellfish) may be less than for an ebb-generation barrage, and may be further reduced for a tidal bar, which operates at an even lower head. A tidal fence design would not impact on water quality.

Figure 12. An impression of the visual impact of a full tidal barrage (left) and a tidal fence

Impacts on fish

Tidal barrages also present a barrier to the movement of marine animals, and so are a particular threat to fish species which migrate seasonally or annually within the Taw. During the SETS investigation, a specific design criterion of the new turbines for a tidal bar was to reduce impact on fish populations. The tidal bar turbines have therefore been designed with a tip speed that is predicted to keep the mortality rate of fish striking the turbines to less than 5%, compared to 30% for the conventional turbines used in a traditional barrage (Rolls Royce and Atkins, 2010). The impact on fish would be further reduced in a tidal fence configuration, as the open structure provides greater opportunities for fish to avoid any contact with the turbines. The likely impact on fish of the different schemes could not be quantified, as such detail is not easily obtainable from the literature, and so a relative scale of impact has been used.

Commercial, military and recreational watercraft

No commercial shipping uses the Taw, but barrages at both proposed sites would impede passage by recreational craft and a Crow Point barrage would also affect access to military training sites, although not those used the most frequently. The Crow Point barrage would, however, be on the upstream edge of the most important sites for amphibious vehicle training, and so there could be morphological changes affecting the sites and navigation could become more hazardous due to strong local currents. Restrictions on vessel navigation would be lower with a tidal fence design. Transit past the barrage is not the only implication for vessels using the Taw. A tidal barrage could create improved upstream conditions for watersports, by increasing the low water level and decreasing current speeds. This could be particularly beneficial in the Taw, as watersports groups have stated that their members make only limited use of the estuary as it approaches Barnstaple due to the current difficulties of upstream navigation.

Learning opportunity

The different schemes also vary in the potential they present as a learning opportunity in both engineering and science. Significant cognitive development value would be obtained were a tidal fence or tidal bar to be piloted, as these have not yet been trialled anywhere.

Energy costs

The relative cost of energy from each of the schemes was considered, as differences in the capital costs of the plant and the expected energy output affect the likely cost per unit of electricity. Ebb-only generation at Crow Point was taken as the baseline, as longer barrage options in a given estuary and ebb-only generation usually offer the lowest cost per kWh (Burrows et al., 2009; Halcrow Group et al., 2009; Parsons Brinckerhoff, 2008a). The study by Binnie and Partners (1989) put the unit cost of electricity from a Taw barrage (at Crow Point) on a par with those from barrages in the Wyre and the Conwy, as these are also small schemes, involving a similar length of barrage and energy output. However, the actual cost figures from this research are long out of date, so the costs of energy (at an 8% discount rate) for the Conwy and Wyre were instead taken from Baker and Leach (2006). As the Conwy is a smaller barrage, this was used as a cost estimate for the Isley site, and the longer Wyre barrage was taken as an estimate for the Crow Point site.

In comparing two-way to ebb-only generation, a ratio was obtained from studies of four northwest estuaries, which suggest that the cost per kWh from two-way generation is, on average, 23% higher than for ebb-only due mainly to efficiency losses in two-way operation requiring a larger number of turbines to maintain the same energy output (Burrows et al., 2009). As in the case of habitat loss, the relative cost of energy of tidal fence and tidal bar schemes were obtained from studies of the proposed Aberthaw to Minehead tidal barrage, which suggest that the cost of energy from a tidal fence is 63% higher than for an ebb-only barrage, because the technology is still in demonstration phase, and so is expensive compared to more mature technology of tidal range turbines (Parsons Brinckerhoff, 2008a). Also, the costings assume complete replacement of the fence every 20 years, based on the expected lifespan of a turbine, while a barrage option is designed to last 120 years, albeit with scheduled maintenance (Parsons Brinckerhoff, 2008a).

Conversely, for a tidal bar scheme the cost of energy may be 25% lower, because the turbines will not have to accommodate such a high energy peak and the bar will generate for a longer period in each tidal cycle (with high turbine efficiency in both directions) (Rolls Royce and Atkins, 2010). The capital cost of a scheme is driven by the rated power, so reducing this peak will reduce the cost of components (Clarke et al., 2006).

The cost per unit energy ratios were converted into the annual premiums a household in the South West would pay compared to the baseline case. The baseline case, rather than the current energy price, was used as the purpose of the study is to consider the relative changes resulting from different schemes. The conversion was based on the average electricity consumption figure referred to above: i.e. the price difference (in p/kWh) suggested by the Severn barrage options was multiplied by the average annual domestic energy consumption (in kWh) of a home in the southwest of England. This approach clearly simplifies the cost calculation; any barrage would be part of the energy mix supplied through the grid, so the barrage energy costs would be incorporated into wider energy costs, and tariffs set accordingly. Thus, those living closest to the barrage would not be treated differently from other customers of the electricity supplier: energy pricing is generally blind to the generating source and the consumer's location.

Reducing the number of attributes to be considered

The purpose of the study is to determine a monetary value for estuarine mudflats, and a tidal barrage scenario is the tool through which this can be achieved. The range of impacts (positive and negative) that would result from a barrage also provides the opportunity to evaluate trade-offs between environmental and social goods, but the scope of this latter component of the research must be constrained in order to make the exercise practicable. Table 6 contains too many attributes and levels to be used directly in a valuation study without placing an excessive cognitive burden on many respondents. A choice experiment would allow the largest number of attributes to be assessed, but suggested best practice would constrain even this to trade-offs between no more than six different attributes (Bateman et al., 2002).

The number of homes powered and greenhouse gas reduction are both alternative ways of expressing the total annual power, so any valuation need only include one of these three attributes. The attributes affected by a tidal energy scheme suggest that scenarios could be presented that trade-off one environmental parameter against another, thus allowing relative preferences for intertidal habitats, fish populations and water quality to be assessed. However, in a realistic scenario, these trade-offs do not occur, as the scale of the impact on intertidal habitats, water quality and fish passage is the same for each tidal energy option: a scheme resulting in a large loss of intertidal area also causes a high impact on fish and the greatest deterioration in water quality.

Given this inter-relationship, a single indicator could instead be used as a proxy for all these environmental variables, against which other energy scheme attributes could be compared. Intertidal habitats are a particular focus of the study due to the current lack of empirical valuation studies. Water quality could potentially be valued more effectively by considering the increased costs of shellfish production or the impacts on public health that result from increased pollution. Similarly, estimated population changes and market prices could be used to value the impacts on migratory fish.

Given the importance of recreation and tourism in the area, it is particularly pertinent to assess how an ecological variable such as habitat loss is traded off against increasing upstream watersports potential. However, this comparison may cause difficulties in experimental design as, in realistic scenarios, the two attributes are directly correlated, with higher watersports potential resulting from increased habitat loss, therefore making it difficult to determine which parameter is driving the choice.

It has been suggested that minimising visual impact is a particularly important criterion in public perception of renewable energy schemes (SDC, 2007), so it could also be useful to determine whether that finding is replicated in this context. Flood defence is an important local policy issue (Vernon, 2010), and the provision of this ancillary benefit has implications for the wider economics of a tidal barrage scheme as it could negate the need for other flood defence expenditure. The value placed by the public on flood defence as an attribute could therefore provide useful insights

Payment method

The final component of the survey scenario is the vehicle through which payment for the environmental good would be elicited, and there are different problems associated with the different payment options. Voluntary payments such as donations introduce the potential for free riding: those choosing not to pay will still benefit providing someone else makes the necessary payment. However, where respondents are faced with coercive payments (national or local tax, fee or price increase) they may object to increases in principle or be hostile to the agency collecting the payment and so refuse to engage in the valuation exercise (Bateman et al., 2002). Split sample surveys also show that willingness to pay can vary significantly depending on the payment vehicle (see Ivehammer, 2009, for a review).

A premium on household electricity bills is a realistic payment vehicle for this study as it directly connects the price with the service provided, and it has been shown that, in general, rates of protest are significantly lower where surcharges to existing bills are used compared to all other payment vehicles, including taxes, donations, funds or fees (Meyerhoff and Liebe, 2009). However, there remains the potential for protest, especially given that energy prices may already be perceived as high and, as electricity is an essential good in current society, respondents may be reluctant to impose increased energy costs on those on low incomes. A tax (which would then be used as a subsidy for renewable energy producers) is an alternative option. A voluntary payment does not seem appropriate in these circumstances; were a tidal energy scheme to go ahead, people would be unable to opt out of receiving their electricity from it.

5.3 Focus Group Consultations

Having quantified the magnitude of plausible changes across a spectrum of barrage parameters, determined those thought to be most pertinent and considered payment vehicles, the next step was to assess how members of the public perceived the various issues. This was considered an essential stage in the design of the survey instrument as the literature provides insufficient insight into how members of the public were likely to respond.

The method chosen to achieve this participation was to hold focus group meetings at which the issues could be discussed by a small group of people living near to the Taw Torridge estuary. The aim of the focus groups was simply to inform the development of the survey instrument that would be used for the empirical research, they were not used as a means to collect data relevant to the research hypothesis. The use of focus groups is not without criticism, particularly that they can be confrontational, with group members commenting on, and potentially challenging, each other's point of view (Kidd and Parshall, 2000) and participants with particularly strong views may influence the responses of others (Schindler, 1992). Undertaking multiple focus groups can overcome this issue of individual dominance.

The specific objectives of the focus groups were to discover levels of knowledge amongst the general public (and hence the information that would need to be provided to them); how barrage costs and benefits were perceived and prioritised; reactions to different payment vehicles; and acceptable levels of payment and habitat loss. Throughout the session, different techniques were used to obtain information from the group, including using shows of hands to place respondents in particular categories (such as level of knowledge), jointly brainstorming (to list different methods of electricity generation, for example) and providing the opportunity for individuals to write down their suggestions in isolation before a group discussion (for example, in ranking barrage attributes).

Two focus groups were held in central Barnstaple on 31 January and 5 February 2011, involving 12 participants in total, although they will be considered henceforth as a single group, as the similarity in the views expressed does not necessitate making any distinction between the two meetings. Participants were recruited in two ways: through local conservation and watersports groups, as users were to be an important survey target group, and also through the Friends association of local secondary schools in order to better reflect the views of the wider public. Men and women were evenly represented, and while most participants were retired, the groups did include professionals in their 40s and also one young person aged about 20.

General discussion appeared to show a broad range of opinion within the group. Participants were generally pro-environment although this was clearly not the prime motivation for at least one participant, who specifically expressed disinterest. The group members were also generally in favour of renewable energy, but there was also support for nuclear power and fossil fuels.

Important features of the Taw Torridge

The attributes of the Taw Torridge estuary considered by the participants to be important included those related to its wildlife, specifically the presence within the estuary of marine life and birds. The estuary was identified as a unique and protected area, and its specific ecological role as a fish nursery was identified. The wider importance of the estuary as the transition zone between rivers and the sea was highlighted and its role in controlling and dispersing freshwater, particularly in relation to acting as a flood water valve, was also emphasised.

The perceived beauty of the area was important to participants, as were the opportunities for education and for recreation, both in the water and on the coast (particularly dog walking). The contribution of the estuary to the local economy was identified as a further important feature, especially tourism, commercial shipping into Bideford, shipbuilding and fishing. The role of the estuary as a military training site was also highlighted.

Level of knowledge about renewable energy

Half of the participants felt they had a moderate level of knowledge of renewable energy in general, and the rest of the group was evenly split between those who felt they were well informed and those knowing only a little. The participants felt much less well informed about tidal energy specifically, with over 80% of the group reporting a low level of knowledge. However, when the specific attributes of tidal energy were later discussed, there appeared to be a moderate level of awareness of some of the main issues related to tidal power: the environmental impacts and the relative advantages and disadvantages of current turbines compared with barrages.

Methods of electricity generation

The group were asked to suggest different methods of electricity generation, and then, from these nine options (Figure 13), to rank the three methods that they would most like to see prioritised within the UK's energy mix. They were also asked to rank these in order of preference, and to explain the reasons for their choices. Comments made by group members about the issue in general, rather than specific generation methods, included statements of preference for renewables over fossil fuels because i) carbon emissions would be reduced and ii) the extraction of fossil fuels is environmentally damaging. The dwindling supplies of fossil fuels and the need for investment in energy sources that would not run out were also highlighted. Perceived disadvantages of renewables in general included the intermittency of supply, and the essential need for energy storage so that the timing of supply could better match that of demand.

The ranking exercise was influenced by individual participants' level of knowledge. In particular, certain respondents felt that they could not include wave power or bioenergy amongst their three preferred technologies as they lacked understanding of the technology. Also, although tidal current turbines and tidal barrages, and on- and offshore wind were each listed separately in the initial exercise, participants did not always feel able to rank them separately, and so they were combined into generic 'tidal' and 'wind' power.

Tidal power was chosen by the greatest number of participants (Figure 13). Those participants who did distinguish between tidal current turbines and barrages showed a strong preference for tidal current options, although the large quantity of energy that could be generated by a barrage was given as a reason for preferring that particular method. The most frequently cited reason for including tidal power as a preferred option was the constant nature of the resource. Tidal power was also seen to be an appropriate method locally as the Taw Torridge is in a coastal region. Disadvantages of tidal power were seen as the environmental impacts and the possible high cost.

Despite its relatively high occurrence at some level within participant choices, tidal power featured only once as the first choice (most preferred) method of electricity generation. The method chosen most often as the first choice was solar photovoltaic (PV) panels. Participants cited very similar reasons for this choice, namely its application in household-level microgeneration, which allows everyone to be engaged and raises awareness of household consumption. Solar PV was also thought to be the least intrusive in terms of social impact, and the cleanest and most economic technique. The potential to import electricity generated by solar panels elsewhere in Europe was also mentioned.

Wind power was chosen by the same number of participants as solar PV, although it featured less regularly as a first choice. There was some indication of greater preference for offshore wind, because of the high potential capacity. The visual impact, even of offshore wind, was cited as a disadvantage. Other methods of renewable electricity generation featured less regularly in participants choices. These included hydroelectricity, which was thought to offer good energy storage options, and geothermal, the constant nature of which was perceived as an advantage.

Bioenergy was supported particularly if it involved producing energy from waste, as this was a solution to two environmental issues. Wave energy was favoured because generating periods do not coincide exactly with those of wind power and so better coverage would be obtained.

Nuclear power was the most popular non-renewable technique, and was the first choice of two participants. Group members tended to feel that nuclear power was something that was necessary for the short-term, but which they wanted to see phased out. Reasons for supporting short-term nuclear power were its role in the supply of base load, the use of proven technology, and the admission that renewables alone cannot provide enough electricity at present. A more generally pro-nuclear stance was expressed, with reasons for supporting this method being the perceived controllable nature of the waste, requirement for only small amounts of uranium, reusable nature of the uranium, and the potential for building power stations in remote locations or on existing sites.

Coal also featured within the list of participants' preferred methods, although this was not anyone's first choice. The main reason for these choices were that the UK has large stocks of coal (and so energy security and local economies would be improved), and also that no electricity storage is required. Technological advances in reducing the CO_2 emissions from coal were also highlighted as important reasons for choosing this method, and one participant did state that there is skepticism within the scientific community about the links between CO_2 emissions and global warming.

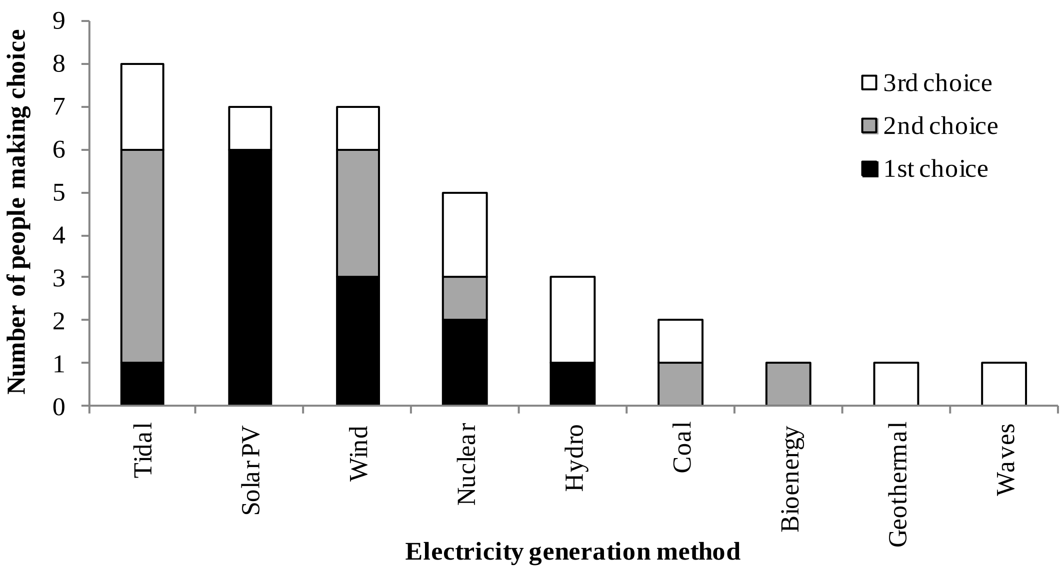

Figure 13. The methods of electricity generation preferred by focus group participants

Attributes of tidal power projects

Participants were asked, individually, to list all the attributes that would be important to them in considering a specific tidal power project, and the responses were discussed within the group. The amount of power generated was very important, particularly in the context of energy needs and the relative quantities being supplied by other renewable sources. Cost was also a central issue, which participants sought to evaluate in a number of ways: the capital cost, operating costs, cost of power, return on investment and cost relative to other renewables. The durability and lifespan of the scheme were also important attributes, and were linked by many to the cost considerations. Members of the group also wanted to know the overall CO_2 emission for all stages of the scheme, and what methods would be used to provide back-up generation when the plant was not operating at full capacity.

Participants also stated that it would be important for them to know about specific advantages and disadvantages, including the environmental and visual impacts, noise levels and other possible ways in which local residents could be disturbed. The impact on shipping and other areas of the local economy were considered important, as was the effect on watersports and the potential for a transport link across the barrage. The group were concerned about the impacts of the construction phase and the materials that would be used in building the scheme, and also about decommissioning, citing the issues related to the former Yelland Power Station (particularly related to hazardous waste) as an unsatisfactory example. The exact location of the barrage would also be an important component of the evaluation process, as only then could the specific impacts on the hydrography and ecology, and the potential for transport links be effectively considered.

Prioritisation of barrage advantages and disadvantages

As a group, the participants identified the five advantages and five disadvantages that they considered most important. The perceived advantages were power generation; improved water recreation; flood control; transport link; and tourism value. The creation of local jobs was also suggested as an advantage, but this was not ultimately ranked, as it was perceived as only providing significant benefit during the construction phase. The most important disadvantages were: impact on habitats; restrictions on boat access; decreased water quality; visual impact; and collision risk to marine life. Participants also queried whether there would be a build-up of litter or debris upstream, but, again, this did not ultimately feature in ranking lists. That visual impact is a disadvantage was contested, as one member of the group pointed out that a barrage could enhance the view upstream by keeping more water in the basin. Another participant also mentioned that passage through a lock might be something recreational users would enjoy (as they do when passing through canal locks) rather than feel impeded by.

Participants were then asked to rank the three advantages and three disadvantages that were most important to them, in order of importance. The production of energy was rated the most important advantage by all but one participant (Figure 14). Flood defence was also important, as there is a high risk of flooding in the area, and this was ranked as the second most important advantage by most participants. Benefits to local economy through tourism were important to half of participants, although were not considered by any as the most important consideration. The other ancillary benefits of a new transport link and increased watersports potential were each rated as important by just under half the group, although mostly these were ranked as the third most important attribute.

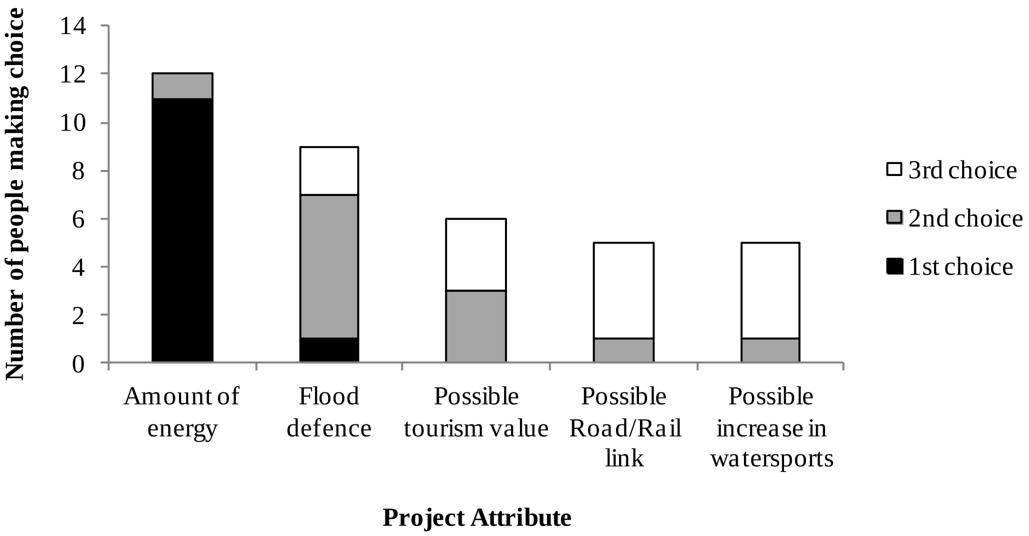

Figure 14. The relative importance to focus group participants of different barrage advantages

When ranking the disadvantages (Figure 15), participants were primarily concerned about the ecological impacts of a barrage, principally the loss of intertidal habitat, which was ranked as the most important disadvantage by over half the group. Possible deterioration in water quality and the collision risk to fish also featured regularly as the greatest disadvantage. Protecting the marine environment was considered important because the estuary is a Site of Special Scientific Interest (SSSI) and also because so much of the economy is supported by tourism which depends on the natural environment. Nearly half of the group had some concerns about the visual impact of the barrage structure, although it was the most important consideration for only one participant. The possible restrictions on boat passage past the barrage were also important to nearly half the group, but in most cases featured only as the lowest ranking choice.

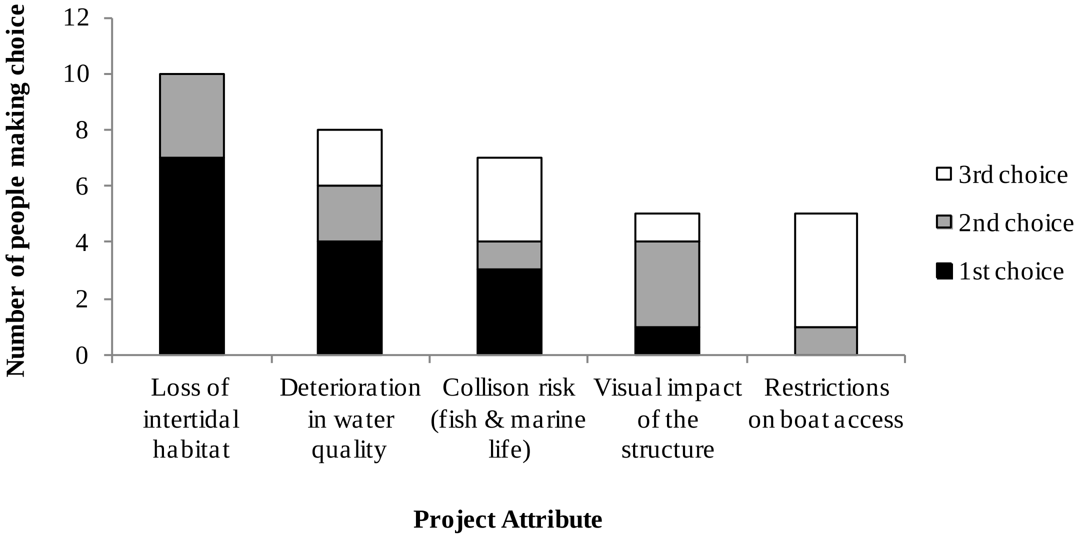

Figure 15. The relative importance to focus group participants of different barrage disadvantages

Payment vehicle for the collection of barrage cost premiums

It was explained to the group that it was possible to design tidal power schemes to minimise impacts or maximise benefits, but that the preferred design may not be the cheapest option. The group, as a whole, was then asked for their opinions on the most appropriate payment vehicle with which to collect any premium related to the preferred scheme: their electricity bill, or a tax, which would then be used to subsidise the energy company.

A clear majority of the group preferred the use of their electricity bill as the payment vehicle (only one chose a tax, and one preferred a mixture of the two). Electricity bills were considered to be fair, and were also favoured due to the direct link to the service provided. Also, increasing bills was considered a good way to make people more aware of their energy usage and the associated issues. There was scepticism about taxes being an appropriate payment vehicle, as participants felt that they are rarely ring-fenced for the purpose for which they are collected. One participant expressed some anger that there should be any additional charge at all, stating that enough environmental taxes were already being collected through, for example, airline surcharges.

Willingness to pay for preferred barrage attributes

Participants were presented with a list of five attributes, which had been identified previously as important considerations in barrage design. They were then asked to write down, individually, the maximum amount they would be prepared to pay as an annual premium on their electricity bill to secure a barrage design which ensured that the preferred attribute would be provided.

Of the five attributes, preventing deterioration in water quality was the only one that elicited some level of willingness to pay (WTP) from all participants; the WTP for each of the other attributes was £0 for at least one participant. Water quality did not elicit the greatest WTP of any attribute, although the highest value suggested for it (£50) was also the modal value for this attribute. The modal WTP for the protection of intertidal habitats was also £50, but for this attribute, participants were prepared to pay up to £100 per year, which was the highest amount suggested for any attribute. £100 was also the highest WTP for two other attributes: a low impact on the view and improved watersports potential, although for both of these attributes the modal value was £0. It would appear therefore that watersports potential and visual impact were not of great concern to many people, but they can provoke significant reactions in those to whom the attribute is of particular concern. Protection of intertidal habitats, on the other hand, appears to be of more serious concern to a greater number of people. Maximising flood protection elicited the same maximum WTP as did minimising impact on water quality (£50). However, the modal value for this attribute was considerably lower at £10.

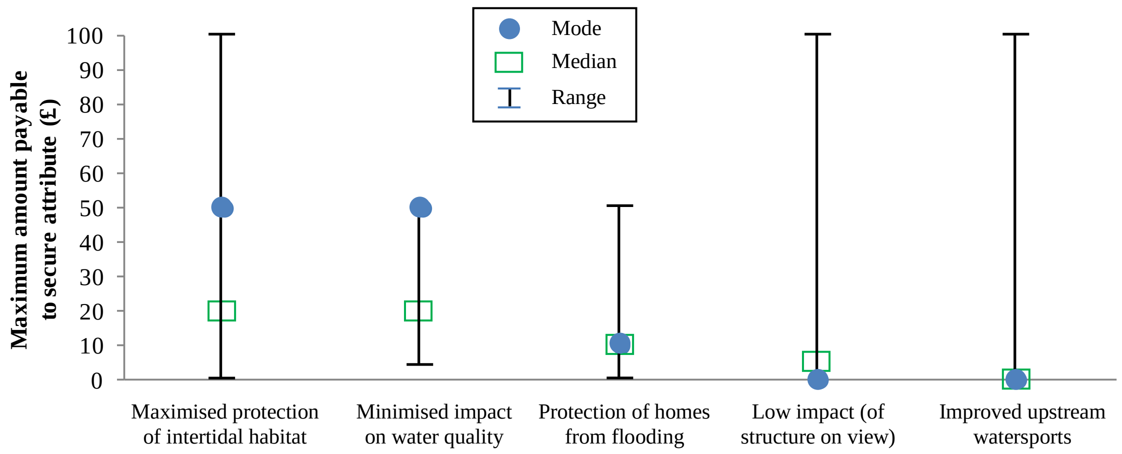

Figure 16. The mode, median and range of values expressed by focus group participants as the maximum annual premium they would be prepared to pay on their annual electricity bill to secure a desired attribute

Tolerable level of intertidal habitat loss

The focus group participants were also asked to specify the maximum loss of intertidal habitat they would tolerate if a tidal power scheme were to be constructed in the Taw Torridge estuary. There was a definite preference within the group for intertidal habitats to be protected in their entirety, but this was coupled with the acceptance that some degree of habitat loss would be a likely consequence of any tidal power project. It was also pointed out that the estuary had already been changed by past man-made impacts, and that it was undergoing natural changes.

One participant categorically refused to accept any loss of habitat under any circumstances due to the potential impact on bird populations, but the others were prepared to tolerate habitat losses of between 15% and 30% of the current level. Most applied caveats to their decision, accepting any loss of habitat only if the barrage was proven to be a sensible and economic strategy, if it could be guaranteed that there would be no impact on the remaining habitat, and providing other pressures on the estuary would be managed accordingly. Participants also expressed their preference for some kind of mitigation to be applied, for example the restoration of intertidal habitats that had been reclaimed as part of past agricultural developments.

5.4 Summary

Stated preference surveys require a plausible scenario with which the respondents can engage. Feasibility studies for tidal barrages in estuaries around the UK and information from the case study site were used to derive credible estimates for the impacts of different tidal barrage designs within the Taw Torridge. These demonstrated that a sufficient range of barrage attribute values could be obtained to allow scenarios involving different trade-offs to be developed.

Focus groups were then use to determine the relative importance of the barrage impacts to members of the public, and also their perception of wider issues. The focus groups confirmed that members of the public in North Devon are sufficiently engaged with issues related to tidal energy to suggest that a survey on this subject would be viable. They identified the amount of power generated and potential flood defence as the most important potential benefits provided by a tidal barrage, while loss of intertidal habitat and deterioration in water quality were the most important costs. The groups also indicated an upper bound of acceptable habitat loss at 30% of the current area of intertidal habitat in the estuary, and discussions highlighted the existence of an expected protest viewpoint, which was opposition to any loss of habitat at all. Focus group members preferred electricity bills as the payment vehicle and suggested a willingness to pay for individual barrage attributes that ranged from £0 to £100.

These important attributes, preferred payment vehicle and other lessons learned from the focus groups were then used to develop the survey instrument. The design, piloting and implementation of the survey are described in the following chapter.

6 Methods: Survey Design, Implementation and Analysis

6.1 Introduction

The preceding chapter explained the process of preparing plausible barrage scenarios for the Taw Torridge and using focus groups to determine which issues were particularly important to members of the public. This chapter builds on those foundations and describes the survey instruments and data analysis techniques used in the empirical assessment. As outlined in Chapter 4, the study used stated preference methods because the viewpoint of members of the public has not yet been adequately assessed in previous studies of tidal barrage developments. In particular, stated preference methods allow non-use values to be captured: at present there is no information about these values for estuarine mudflats.

In the absence of precedent findings against which to compare the estimate, concurrence between multiple methods can improve the credibility of empirical assessments. Thus, willingness to pay (WTP) to reduce estuarine mudflat loss was derived using two techniques: contingent valuation and a choice experiment. In addition, a multi-criteria analysis tool, the Analytic Hierarchy Process (AHP) (Saaty, 1980), was also used to assess relative preferences for different barrage attributes and so elucidate the basis for the elicited WTP in the CV questionnaire. This chapter describes and discusses in detail the specific application of each technique, including the reasoning behind aspects of the survey design.

This chapter discusses the survey design, including the introductory questions on attitudes to energy issues, the use of a payment card to elicit WTP in the contingent valuation, and the assessment of scope sensitivity. Factors influencing the experimental design of the choice experiment are described, and the issues surrounding selection of an appropriate 'no choice' alternative are discussed. This chapter also describes a pilot survey that was undertaken to test the questionnaire, and the implementation of the main survey using face-to-face and online approaches. The data analysis techniques are outlined, including descriptions of the econometric models used and the theoretical basis of the Analytic Hierarchy Process.

6.2 Survey Instrument Design

Introductory questions

The focus of the survey was to derive an empirical monetary value for estuarine mudflats using two different stated preference methods and incorporating the AHP to provide further information through which to explore preferences. However, it was necessary to introduce the survey with questions on broader, related subjects to accustom respondents to the interview process prior to the valuation questions, to establish the credibility of the scenario to the respondent (and hence signal potential protest behaviour), and to gather other information that may have a bearing on the participant's later responses, particularly their WTP.

A split sample approach was taken, with a combined contingent valuation and AHP exercise carried out with one group of respondents, and the choice experiment study conducted with a separate group. With the exception of the valuation exercise, both questionnaires (reproduced in full in Appendices II and III, along with their respective show cards) were identical. The first section sought to establish how often respondents from outside the study area visited the Taw Torridge, in order to determine their familiarity with the site. Climate change, its perceived link to fossil fuels, and energy security were introduced in the second section, before respondents were asked to register, on a 5-point Likert scale, the level of their agreement with statements about these energy issues. Respondents were also asked whether they generated their own electricity, and how well informed they were about tidal barrages. Respondents' attitudes to energy issues were thought likely to have a particular bearing on their responses, as their perception of climate change and its causes were expected to influence their acceptance of the potential necessity of a barrage. An explanation of the operation of tidal barrages and their potential impact on coastal mudflats and bird populations was also provided prior to the valuation exercise. This information included highlighting that potential substitute feeding grounds would be available for some species.

After the valuation section, all respondents who expressed a zero WTP were asked follow up questions to determine whether these were genuine zero bids or protests against the scenario. The questions sought to determine whether respondents objected to barrages in general, to paying for barrages or to paying for any form of renewable energy, or whether they could not afford to pay even if they preferred the less-damaging barrage. Respondents indicated their level of agreement with each of the statements on a 5-point Likert scale. A subsample of those stating a positive WTP were also asked these questions, in order to determine any differences in the responses.

The questionnaires concluded with the collection of socio-economic information about the respondents, including the frequency and nature of their recreational use of coastal environments as well as other parameters such as gender, age, income, employment, education and size of household. The role of factors such as income, education and level of use in predicting WTP for environmental goods is well documented (López-Mosquera and Sánchez, 2011). Following Longo et al. (2008), a further section was included in the face-to-face survey, in which the interviewer recorded her perception of the respondent's level of understanding, difficulty and annoyance. Additional information on the survey administration such as the method of interview delivery (in home, doorstep, street), the date and the weather was also recorded by the interviewer.

Contingent Valuation

For the contingent valuation, respondents were asked how much they would be willing to pay each year in increased energy costs in order to secure a barrage design that reduced coastal mudflat loss. A recurring, instead of a one-off, payment was considered most appropriate, given that a barrage would provide electricity on an ongoing basis, rather than being a discrete intervention which could be funded from a fixed sum. It was explained in advance to the respondents that they would be told about different barrage scenarios in order to avoid the inconsistencies in scope sensitivity that may be observed with stepwise disclosure (Bateman et al., 2004).

Respondents were first introduced to the baseline barrage, which would cause the loss of 210 hectares of coastal mudflat (42% of the total coastal mudflat in the estuary), but would produce energy at the same cost as now. The area of habitat lost was based on calculations of a worst-case scenario. The first valuation scenario involved asking respondents for their willingness to pay (WTP) for an alternative barrage design, which, while still producing the same quantity of energy, would reduce coastal mudflat loss by 70ha compared to the baseline. Respondents were reminded to consider their existing financial commitments when deciding how much they could realistically afford to pay.

The WTP format is recommended over willingness to accept (WTA) because the former provides a more conservative estimate of value: respondents are thought more likely to significantly overstate the level of compensation they require than they are to vastly exaggerate the amount they would pay to achieve a change, so WTP reduces the upward bias in the value estimate (Arrow et al., 1993). Also, WTP was preferred because WTA tends to elicit more protest responses (in some cases 50% or more) (Mitchell and Carson, 1989). Finally, WTA values tend to decrease and approach WTP as the respondent becomes more familiar with the scenario while WTP values remain more stable (Mitchell and Carson, 1989) suggesting that the WTP estimate is more reliable.

Elicitation method

WTP was ascertained using a payment card, which, in addition to 35 listed values, provided the opportunity for respondents to choose more than the maximum value shown on the card, and subsequently to state their exact WTP. It is argued that the payment card method places a lower cognitive burden on respondents compared to open-ended formats (Kallas et al., 2007) and so potentially reduces non-response (Cameron and Huppert, 1989). It is also a more efficient means of maximising WTP information compared to dichotomous choice (Lindhjem and Navrud, 2011). Furthermore, yea-saying and anchoring effects are likely to be reduced with payment card approaches (Boyle, 2003).

Payment cards are not without disadvantages, in particular that there is the potential for incentive incompatibility (Champ and Bishop, 2006; Lienhoop and Ansmann, 2011). This arises because respondents are offered a range of values to choose from (rather than just a single value as with dichotomous choice) and so have a greater opportunity to act strategically. Also, payment cards are potentially subject to bias if the range is inappropriately truncated (Whynes et al., 2004). However, range and centering biases are not apparent if the upper limits of the value distribution are sufficiently high (Rowe et al., 1996). The range of values displayed on the payment card used in this study was determined following focus group discussions (Chapter 4), and the upper limit was set at twice the maximum value stated by focus group members to ensure that an appropriate range was used.

Testing scope sensitivity

Respondents who expressed a positive WTP were then presented with a second scenario designed to test for scope sensitivity, which would would support the validity of the elicited WTP as a 'true' economic value and aid understanding of the transferability of the results. An internal scope test was used because this has greater statistical power than an external test (Carson et al., 2001), and requires a smaller sample size. This second scenario was a repeat of the first, except that respondents were now asked for their WTP to reduce habitat loss by 140ha, twice that of the first scenario. As mentioned above, this second scenario had already been introduced prior to any valuation questions being asked, in line with good practice (Bateman et al., 2004). The contingent valuation section closed with questions to determine relative preferences for wind and nuclear power compared to barrages.

Analytic Hierarchy Process

The purpose of the Analytic Hierarchy Process section of the questionnaire was to determine relative preferences for different components of a barrage design. Also, the weights derived from this would serve as a metric to define the importance of mudflats to each respondent, as information on attitudes to the environment is necessary for the effective interpretation of valuation responses (Kotchen and Reiling, 2000). Flood protection and improved watersports potential were introduced to respondents as two possible benefits of barrages, to contrast with the potential costs (mudflat loss and additional cost of electricity) which had already been explained to the respondents in earlier sections of the questionnaire. The attributes were described to respondents and also illustrated pictorially, and the respondents were asked to make pairwise comparisons between them using a scale of relative importance (see Figure 17 for an example). The AHP assessment was confined to four attributes to prevent the survey becoming too long: four attributes require six pairwise comparisons, while five would require 10, and six attributes, 15 comparisons.

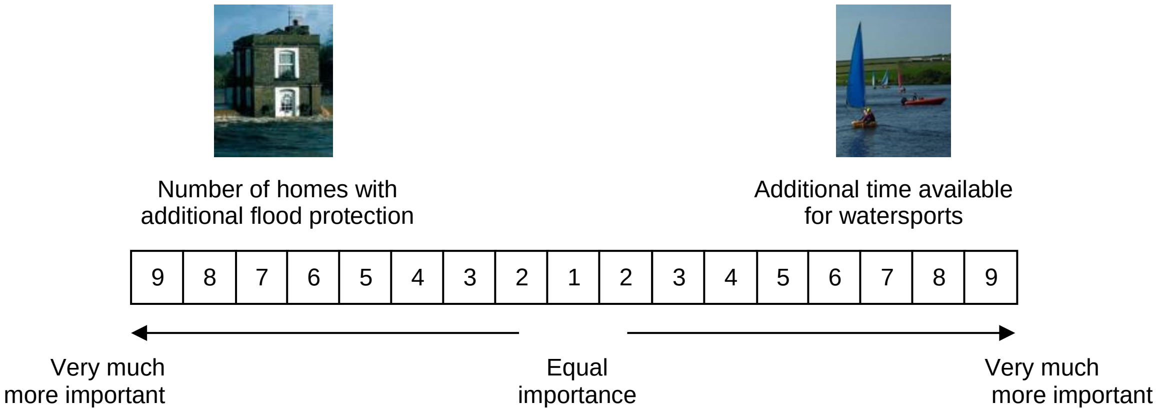

Figure 17. An example of an AHP pairwise comparison presented to respondents

Choice Experiment

A choice experiment was used to determine the extent to which WTP to reduce estuarine mudflat loss differed when an alternative method was employed. Also, the choice experiment allowed WTP to be determined for multiple barrage attributes, providing additional insights to complement the AHP (which had assessed relative preferences in the absence of monetary values for the attributes) and generating values for additional attributes that could be used in cost benefit analysis. The choice experiment scenario was designed to match that of the contingent valuation as closely as possible, although there were differences in the decision frame: the choice experiment considered habitat loss relative to the current level of provision, whilst the starting point for the contingent valuation was a 'worst-case' barrage scenario.

The design of the choice experiment was influenced by a detailed review of the literature. An important constraint was the sample size, which was restricted to 120 respondents due to cost considerations. Smaller sample sizes require more choices per respondent as well as placing limitations on the number of levels per attribute. A sample size of 120 respondents would be acceptable if each made eight choices and no attribute had more than four levels, as described in Johnson's formula (Orme, 2010) (Equation 6.1),

$$\frac{ntb}{l} \geq 500 \qquad (6.1)$$

where n is the number of respondents, t the number of tasks, b the number of alternatives per task not including the 'neither' alternative and l is the number of analysis cells. When considering main effects, l is the largest number of levels for any one attribute, or, if two-way interactions are also being considered, l becomes the largest product of levels of any two attributes.

As the number of choice sets increases, the quality of responses may improve as the interviewee becomes more familiar with the task, or it may decline as a result of respondent fatigue (Johnson and Desvousges, 1997). No consensus on the optimum number of choice sets has yet emerged, and there is contradictory empirical evidence as to whether increasing the number of choice sets adversely affects WTP estimates (Bech et al., 2011; Carlsson and Martinson, 2002; Sattler et al 2003; Hensher, 2006). Eight choices per respondent is typical (Louviere et al., 2000; Ryan and Gerard, 2003) and was considered appropriate for this research.

The respondent's reaction to the choice task is also a factor of its complexity in terms of the number of attributes and the number of levels per attribute. Increasing task complexity compromises choice consistency (see DeShazo and Fermo, 2002, for a review) and dramatically increases the probability that the respondent will ignore certain attributes when making his decision (Hensher, 2007). In order to limit the complexity of the choice task, four attributes were used. The choice experiment did not exactly duplicate the attributes used in the earlier AHP assessment, however. Mudflat loss, flood protection and annual increase in electricity costs were maintained but watersports gain was excluded as it is not independent of habitat loss. The final attribute used in the choice experiment was the amount of power produced by the barrage, as no information had yet been obtained on how greenhouse gas emission reduction is traded-off against habitat loss. The words to describe the power attribute were carefully chosen to ensure that respondents understood that power was a proxy for carbon emissions reduction, not the cost of electricity: "*Using a tidal barrage to produce renewable electricity would mean that less fossil fuels are required, so carbon dioxide emissions would be reduced. The scale of this reduction can be thought about in terms of the number of houses that could be powered by the barrage*".

Two levels were used for each attribute (Figure 18), with the exception of price, where two levels were considered too restrictive given the range of WTP suggested by the focus group discussions and the outcome of the contingent valuation. The cost attribute was therefore given four levels: £3, £12, £48 and £196, to align the choice experiment with the contingent valuation and the focus group outcome. The small number of attribute levels helps to reduce complexity, and also permits the full factorial design to be used, which is beneficial as it ensures that all attributes are truly independent (Louviere et al., 2000).

The full factorial design had 2^3 x 4^1 (= 32) combinations of attribute levels. The combinations were to be paired to produce two choices and a status quo (no choice) option in each choice set (Figure 18), which requires at least 16 choice sets if every combination of attribute levels is to be included. However, using only 16 choice sets presented a problem as each respondent would be required to make eight choices in order to produce a sufficient sample size. The problem arises because at some point during the choice set the respondent would be presented with a barrage configuration she had seen before (in terms of the level of flood protection, watersports and habitat loss) but that differed in price from when it appeared in an earlier choice set. This creates a potential plausibility issue. The problem was addressed by creating four blocks of eight choice sets, using all 32 possible combinations with a shifted design (altering the attribute level by one step) to generate the second choice in the pair. Careful blocking ensured that there was no duplication of barrage configurations within each set and also that the positioning of each attribute level varied within the pair (e.g. the first alternative did not always contain the greatest level of flood protection).

	Barrage A	**Barrage B**	**Neither**
Additional renewable energy (number of homes powered)	 21,000	 14,500	None
Additional flood protection (number of homes)	 1,900	 2,400	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	 140 (28%)	 70 (14%)	None
Additional cost of electricity each year due to the barrage	£12 (£1 per month)	£48 (£4 per month)	None
Which option would you choose?	☐	☐	☐

Figure 18. An example of a choice card.

A 'no choice' option was included so that respondents were not forced to choose one of the hypothetical scenarios if their true preference is for the status quo (Bateman et al., 2002). There is a clear consensus for this within the literature: in a review of 20 recent choice experiments, 88% of the studies included a no choice option. However, the no choice scenario can be expressed in different ways, and the reasons why it has been formulated in a particular way are often not well elucidated.

In some examples, a specific quantitative or descriptive level is given for each attribute that accurately reflects what is happening now and usually references the existing degraded environmental attribute that would be improved by an intervention (Taylor and Longo, 2010; Birol and Das, 2010; McVittie and Moran, 2010; Westerberg et al. 2010). In other studies the levels assigned to the status quo scenario are based on a hypothetical future (Zander et al. 2010; Kosenius, 2010). Alternatively, authors simply state against each attribute that there would be no change from the current situation (Longo et al, 2008) or provide a general description of the wider implications of no action in the final column of the choice card, without necessarily stating specific levels for each individual attribute (Bergmann et al. 2006). A further example from the literature is to just include a tick box below the choice pairs to allow the respondent to choose the "status quo" or "neither" of the listed choices, with some explanation of the implications of this choice given in introductory text (Ku and Yoo, 2010; Bateman et al. 2002).

Defining the no choice option is not straightforward in this case, because the energy policy context does not allow for 'business as usual' given the UK Government's stated policy of increasing renewable sources in the energy mix, so 'no choice' would effectively imply alternative consequences. Given the small scale of a tidal energy scheme in the Taw Torridge it would be rather extreme to attribute a significant climate change impact to a preference for the status quo. A more realistic consequence is that an alternative form of non-fossil fuel energy, such as a wind or nuclear, would be used instead in order to ensure that carbon emissions targets are met, which would create an alternative set of welfare impacts. An onshore wind farm would be the most likely substitute in this case, given the likely quantity of energy produced.

However, the choice experiment framework does not readily allow for comparison between options with different attributes without overcomplicating the scenario or losing sight of the attributes of interest. A scenario involving both wind farms and barrages is also potentially problematic as wind power is itself controversial, and so the values generated by those choosing a barrage option would represent a combination of WTP to avoid a wind farm and WTP for the barrage benefits. It is also questionable whether it would be credible to state that a wind farm option would result in no additional monetary cost to the respondent. Also, associating the no choice scenario with certain attributes unrelated to the barrage options creates further problems for respondents whose price ceiling for a barrage had been reached, as they would be forced to choose wind (as the 'no cost' option) when this may not reflect their true preference, or to avoid doing so by choosing a barrage option which they could not realistically afford. Therefore it was decided to accept that "none" was an inaccurate description of the implications of a no choice decision but was the best alternative under the circumstances. It was also recognised that the value for energy produced within this context (of a barrage vs no additional renewable electricity) would be a bundle of general values related to renewables: it would not be possible to attribute it to tidal energy specifically.

The design of the hypothetical scenarios is further complicated because energy bills are increasing, and are expected to continue to do so. This issue has to be addressed in order to control the decision frame used by the respondents, otherwise respondents could make their choice based on misconceptions such as thinking that a barrage would cost less than the amount by which they expect their bills to rise, or that the no choice option would mean bills did not increase at all in the future. The introduction to the choice experiment therefore included the following wording: *"The different options will also result in an increase in the cost per unit of electricity, which would mean an increase in your electricity bills. The amount of this increase will also vary with the different options. This increase is in addition to (not instead of) any other factors that may cause your bill to rise. For the purpose of this exercise, please assume that your electricity bill will rise only as a result of the barrage, and that it will remain at its current level otherwise."*

6.3 Pilot survey

It is good practice to undertake a pilot study before the main research is implemented, in order to verify respondents' understanding of the context and specifics of the task, as well as testing other factors such as the length of the survey (Hoyos, 2010). A pilot was therefore undertaken between 9 May and 20 May 2011 involving 16 members of the public. Both the contingent valuation and choice experiments were tested in face-to-face interviews with participants recruited through knocking on doors. The pilot included residents of Braunton and Barnstaple, which are close to the Taw Torridge and also Cullompton, 40 miles away. The latter group was included because (as described in Chapter 5) one purpose of the survey was to determine distance decay effects, and so the pilot was used to confirm that there was sufficient interest from non-residents to generate a suitable sample.

The outcome of the pilot suggested that suitable information was provided for the respondents to engage with the scenario and that they understood the valuation and Analytic Hierarchy Process tasks. Some zero bidding was expected, and 25% of respondents chose the 'none' in the choice experiment or bid £0 in the contingent valuation. The surveys were not overly long, taking 18 minutes on average to complete. Therefore, no major changes were made to the instrument between the pilot and the main survey.

6.4 Main Survey Implementation

Phase One: Analytic Hierarchy Process and Contingent Valuation

Face-to-Face interviews in North Devon and Wellington

Surveys with the general public took place using face-to-face interviews, using the survey instrument presented in Appendix II. Interviewer-administered surveys can induce social desirability bias (Champ and Welsh, 2007), but the presence of an interviewer who could clarify any issues for the respondents was felt to be particularly important in this case as, based on the focus group outcome, it was expected that respondents familiarity with both tidal barrages and intertidal mudflats would be low.

Face-to-face interviews were carried out in several towns and villages bordering the Taw Torridge estuary in North Devon: namely Barnstaple, Braunton, Bideford, Fremington, Yelland, Instow, Appledore and Northam (Figure 19). These were pooled to provide a sample of responses from people local to the estuary in North Devon. Face-to-face interviews also took place in the town of Wellington in Somerset, about 50 miles away (Figure 20), so that any effect of distance decay on responses could be examined. The interviews in both study areas were conducted by professional market researchers in respondents' homes, workplaces and on the street between 16 August and 17 September 2011. The interviewers were supplied by Power Marketing Ltd, an Exeter-based market research company. Quotas were used to ensure that respondents were appropriately representative of gender, age and social groups.

Figure 19. The sites of face-to-face surveys in the North Devon study area

Figure 20. The location of the Wellington survey site relative to the Taw Torridge

Online survey of marine scientists and other academics

The study also sought to assess the influence of specialist knowledge on responses, to further test of the hypothesis that WTP will increase with familiarity (Bergstrom et al., 1990; Cameron and Englin, 1997). The study therefore included surveys with marine scientists ("experts") and a control group of "other academics". This component of the study took the form of a self-administered online survey. A computer-based technique was preferred to a postal survey because it was less expensive and reduced the time needed for data entry, and the level of education of the respondents suggested that there was no need for an interviewer to provide explanations.

The online survey replicated that used in the face-to-face interviews except for the omission of the final section on interviewer perception and survey administration. It was created using the Survey Gizmo online software. Plymouth was chosen as the survey site because it is a hub of marine science, and so offered the largest possible pool of potential expert respondents. Also, Plymouth is in Devon and is on an estuary, so has geographical and ecological features comparable to those of the case study site (Figure 21).

Contact email addresses were obtained from the institutions' websites. An invitation email was sent on 14 September 2011 to 218 email addresses of marine scientists based at the University of Plymouth, Plymouth Marine Laboratory and the Marine Biological Association. A reminder email was sent on 5 October 2011, and the survey closed on 14 October 2011. The survey of other academics was implemented slightly later, with the initial invitation email sent on 26 September 2011 to 277 academics at the University of Plymouth and Plymouth-based staff of the Peninsula College of Medicine and Dentistry. Reminders were sent on 10 and 20 October, and the survey closed on 22 October 2011.

Both sample groups shared Plymouth as a workplace, but respondents were not necessarily resident there. Only the responses of those living in South Devon within 35miles of Plymouth were included in the analysis in order to reduce the potential influence of geographical effects.

Figure 21. The location of Plymouth relative to the Taw Torridge

Phase Two: Choice Experiment

The choice experiment was again interviewer-administered, and the survey was undertaken with members of the public in Barnstaple, Braunton and Bideford between 26 October and 5 November 2011. As for the contingent valuation, professional market researchers supplied by Exeter-based Power Marketing Ltd carried out the interviews, who again used quotas to ensure that the sample was representative of the general public within the area. The introductory and concluding sections of the survey instrument were the same as for Phase One, but the Analytic Hierarchy Process (AHP) and contingent valuation sections were replaced with the choice experiment. The full survey instrument is included in Appendix III.

In addition to the difference in elicitation method, there was a further difference between the choice experiment and the contingent valuation survey instruments. In the latter, only respondents who expressed a zero WTP were asked follow up questions to determine whether these were genuine zero bids or protests against the scenario. In the choice experiment, however, these questions were asked of both the respondents who always chose the status quo option, and also a subsample (n = 22) of the respondents who did select barrage options. This was to explore whether different answers were given by those who were, and were not, willing to pay, and hence to give greater validity to the use of these follow-up questions as a means of identifying protesters.

6.5 Data Analysis

Data analysis was performed using STATA/SE 11.1, except for calculation of the attribute weights from the Analytic Hierarchy Process (AHP), for which an online eigenvalue calculation tool was used (Akiti, 2011). Non-parametric statistics were used in describing sample populations and comparing subsamples. These tests included the Pearson's chi-squared to assess the frequency distributions when comparing subsamples and Spearman rank correlation to investigate relationships between variables that were primarily ordinal. The AHP weights for each attribute were compared between the two survey sites using Mann-Whitney tests, and within each site, Wilcoxon signed-ranks tests were used to determine whether the attribute weights were significantly different from each other.

Analytic Hierarchy Process (AHP)

When using four attributes, an AHP assessment produces six values, one for each pairwise comparison. The pairwise ratings for each attribute are arranged in a square matrix of size *z*, where *z* is the number of attributes (Duke and Aull-Hyde, 2002; Equation 6.2). Each value on the matrix diagonal, a_{ii}, a_{jj},....,a_{zz}, is equal to 1, as it represents the pairwise comparison of each attribute with itself. The ratings given by the respondent are entered above the diagonal, where a_{ij} is the rating of attribute i compared to attribute j. The matrix is completed by pairing each value with its reciprocal across the matrix diagonal, such that $a_{ji} = 1/a_{ij}$.

$$A = \begin{bmatrix} a_{ii} & a_{ij} & \cdots & a_{iz} \\ a_{ji} & a_{jj} & \cdots & a_{jz} \\ \vdots & \vdots & \ddots & \vdots \\ a_{zi} & a_{zj} & \cdots & a_{zz} \end{bmatrix} \tag{6.2}$$

The principal objective of AHP is to convert these pairwise ratings into weights, w_i, w_j, ..., w_z, that express the proportional importance of each attribute to the respondent. Each of the pairwise ratings represents the ratio of the weights for the two attributes in the pair, i.e. $a_{ij} = w_i/w_j$. The matrix *A* (Equation 6.2) can therefore be expressed in terms of these weights ratios (Saaty, 2008; Equation 6.3).

$$A = \begin{bmatrix} \frac{w_i}{w_i} & \frac{w_i}{w_j} & \cdots & \frac{w_i}{w_z} \\ \frac{w_j}{w_i} & \frac{w_j}{w_j} & \cdots & \frac{w_j}{w_z} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_z}{w_i} & \frac{w_z}{w_j} & \cdots & \frac{w_z}{w_z} \end{bmatrix} \tag{6.3}$$

In order to obtain the individual weights as opposed to the ratios, matrix A (Equation 6.3) is multiplied through by a column matrix of the individual weights, w, thus generating Equation 6.4, where z, again, is the size of the original square matrix (Saaty, 2008).

$$A = \begin{bmatrix} \frac{w_i}{w_i} & \frac{w_i}{w_j} & \cdots & \frac{w_i}{w_z} \\ \frac{w_j}{w_i} & \frac{w_j}{w_j} & \cdots & \frac{w_j}{w_z} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_z}{w_i} & \frac{w_z}{w_j} & \cdots & \frac{w_z}{w_z} \end{bmatrix} \begin{bmatrix} w_i \\ w_j \\ \vdots \\ w_z \end{bmatrix} = z \begin{bmatrix} w_i \\ w_j \\ \vdots \\ w_z \end{bmatrix} \tag{6.4}$$

Equation 6.4 can be expressed in the form:

$$(A - zI)w = 0 \tag{6.5}$$

where I is the identity matrix and w is the column vector of the weights defined above.

This is an eigenvalue problem, which is then solved to determine each attribute weight (Saaty, 2008). An z x z matrix has z eigenvalues, and corresponding to each eigenvalue is an eigenvector n elements long, which comprises the attribute weights. For consistent AHP matrices (defined as satisfying the criteria $a_{jk} = a_{ik}/a_{ij}$) there is one eigenvalue of value z and the others are zero (see Saaty, 2008 for a mathematical proof). However, not all respondents wil provide responses that conform to this mathematical definition of consistency, and so inconsistent matrices may be generated. In this case, there will be several non-zero eigenvalues, λ_1, λ_2, ..., λ_{max}, with differences in the corresponding eigenvectors and hence the attribute weights. Under these circumstances, Saaty (2008) advocates that the eigenvector corresponding to the largest eigenvalue, λ_{max}, should be used to determine that attribute weights.

Finally, the eigenvector is normalised by dividing each of the eigenvector components by their sum, to recover the weights on an absolute scale for each respondent (Saaty, 2008). The individual attribute weights can be aggregated to produce the final result for each sample of respondents. The geometric mean is preferred for this aggregation, as the arithmetic mean is considered less consistent with the underlying axioms of AHP (Forman and Peniwati, 1998).

Where inconsistent matrices are generated, a measure of how far the matrix deviates from a consistent response is given by the Consistency Index, μ (Equation 6.6) (Saaty, 2008):

$$\mu \equiv \frac{\lambda_{max} - z}{z - 1} \tag{6.6}$$

The Consistency Ratio can then be determined (Equation 6.7), to compare the respondent's ratings to randomly generated responses (Saaty, 2008).

$$\text{Consistency Ratio, CR} = \frac{\mu}{\text{RI}} \tag{6.7}$$

where RI is the published Random Index: the average Consistency Index from a large number of randomly generated matrices (Saaty, 2008). Saaty (2008) asserts (p265) that the "allowable consistency ratio should be not more than about 0.10". Saaty (1990) cites Vargas' (1982) work on eigenvector distributions as the mathematical basis for this threshold.

Due to the nature of an AHP assessment with four features being compared, the maximum weight that can be ascribed to any attribute is 0.75. This occurs when a respondent always gives one attribute the maximum possible rating and is indifferent to all pairs without that attribute. The technique does not allow for the attributes to which the respondent is indifferent to be given a zero weight. Instead these three attributes each receive the minimum weight ($^1/_{12}$), which restricts the maximum possible weight of the preferred attribute to 0.75.

Econometric modelling: contingent valuation

The goal of econometric models is to show that WTP is responsive to the good being provided, and to determine how socio-economic variables influence that response. Respondents know the factors that influence their decision, but the analyst does not and so has to represent this through a simplified model that captures the most important elements of the utility function (Bateman et al. 2002). The respondent's true utility function has the form $V(Y, C, S, H)$, where Y represents income, C the price of the good, S social and demographic factors, and H the level of provision of the good (Bateman et al. 2002). In the analyst's model the estimated utility function becomes $v(y, c, s, h, \eta)$, where lower case indicates that the factors are not exactly identical to those considered by the respondent, and η represents the part of true indirect utility that cannot be estimated in the simplifying model (Bateman et al. 2002).

Initially, the contingent valuation data was modelled using an OLS regression, as comprehensive diagnostic statistics are available which provided useful insights into the general applicability of regression models. Following Greene (2003), an OLS model assumes that there is a linear relationship between WTP and the explanatory variables x_1-x_k, which is a function of the parameters, β_1- β_k, the constant α (WTP when x_1-x_k = 0) and the disturbance term, ε:

$$WTP = \alpha + \beta_1 x_1 + \ldots + \beta_k x_k + \varepsilon \qquad (6.8)$$

Other econometric models were also used in the preliminary analysis, to address issues such as heteroskedasticity and to improve the fit to the data. Using a variety of models also tests the robustness of the WTP estimates by assessing how the coefficients vary with alternative techniques.

Model 1. The OLS model was run using the Huber-White sandwich estimator. This provides standard errors that are robust, without requiring a formal model of the structure of the heteroskedasticity to be derived (White, 1980). White's estimator is calculated for each parameter in the regression model (Hill et al., 2001) based on the variance estimate for the coefficient:

$$\mathrm{var}(\hat{\beta}) = \frac{\sum\left[(x_i - \bar{x})^2 \hat{e}_i^2\right]}{\left[\sum(x_i - \bar{x})^2\right]^2} \qquad (6.9)$$

where $\hat{e}_i$ is the least squares residual for the *i*th observation.

Model 2. A weighted least-squares (WLS) estimator was applied to the data, which gives a larger weight to the observations with smaller variances so that they have more influence on the estimates obtained (Greene, 2003).

The WLS model was calculated using the wls0 STATA command developed by the UCLA ATS Statistical Consulting Group, which was performed on square root-transformed data. The weighting chosen was proportional to the income variable, using the absolute value of the residuals.

Model 3. The WTP data was $\log_e$-transformed and the OLS regression was re-run.

$$\mathrm{Log}\, WTP = \beta + \beta_1 x_1 + \ldots + \beta_k x_k + \varepsilon \qquad (6.10)$$

Model 4. Respondents were not given the opportunity to express a negative WTP, effectively censoring the data at 0. A tobit model was therefore used to account for this effect, which was censored at the lower bound, WTP_L (Dougherty, 2011):

$$WTP = \beta + \beta_1 x_1 + \ldots + \beta_k x_k + \varepsilon, \text{ for } WTP > WTP_L$$
$$WTP = WTP_L, \text{ otherwise} \tag{6.11}$$

Model 5. Models 1-4 above used the mid-point of the WTP interval to represent an exact WTP. However, it is better practice to perform linear regression directly on interval data, as failure to do so can bias parameter estimates (Cameron and Huppert, 1989). Interval regression can also incorporate left-censored data, and robust standard errors can be applied to address the lack of normality and heteroskedasticity.

In interval regression, the respondent's true WTP is known to lie between the value selected on the payment card, t_{li}, and the next highest value presented, t_{ui}. Following Cameron and Huppert (1989) and assuming that log WTP_i is a linear function of the explanatory variables x_i and parameters β then:

$$\log WTP_i = x'_i\beta + \varepsilon_i \tag{6.12}$$

with ε_i normally distributed with mean 0 and standard deviation σ. The probability of a respondent choosing t_{li} can be expressed as the difference between two standard normal cumulative densities, so that the log likelihood function, L, for n independent observations is:

$$\text{Log } L = \sum_{i=1}^{n} \log\left[\Phi\left(\frac{t_{ui} - x'_i\beta}{\sigma}\right) - \Phi\left(\frac{t_{li} - x'_i\beta}{\sigma}\right)\right] \tag{6.13}$$

where Φ is the standard normal cumulative density function.

Scope sensitivity

A further model was employed later in the analysis, as a means of assessing which factors affected the likelihood of respondent's WTP showing sensitivity to scope. The model involved binary data (the presence or absence of scope sensitivity) and so a logit model was used. Following Dougherty (2011), the probability, p, that the explanatory variable, X, will cause a particular outcome is determined by the function:

$$p_i = F(X_i) = \frac{1}{(1 + e^{-X})} \tag{6.14}$$

which restricts p to lower and upper bounds at 0 and 1 respectively. The marginal effect of X on probability, $f(X)$, is determined by:

$$f(X) = \frac{\mathrm{d}p}{\mathrm{d}X} = \frac{e^{-X}}{(1 + e^{-X})^2} \tag{6.15}$$

Logit models can be used with multiple explanatory variables, in which case X becomes:

$$X = \beta + \beta_1 x_1 + \ldots + \beta_n x_n \tag{6.16}$$

Econometric modelling: choice experiment

There are differences in the underlying economic theory of contingent valuation and choice experiment approaches, as the latter is based on the assumption that utility is derived not from a good directly, but from the different attributes of that good (Lancaster, 1966). In a choice experiment, respondents are presented with a choice of alternatives, and (within the constraints of their income) will select the alternative with the combination of attributes that provides the greatest utility.

Pre-treatment of the data

Within this study, the magnitude of the levels for the different attributes varied considerably: 70–140ha of habitat lost, 1,900–2,400 houses protected from flooding, and 14,500–21,000 homes powered. These values were therefore normalised prior to analysis of the data, by dividing through by the smaller attribute level in each pair.

Conditional logit model

The data was initially assessed using a conditional logit model, a variation of the multinomial logit model (McFadden, 1974) which is appropriate in situations where the utility function depends on the characteristics of the alternatives, as well as on the attributes of the decision maker. Following Train (2009) the formula for choice probabilities, where the probability P of individual n choosing alternative i from J alternatives, is:

$$P_{ni} = \frac{\exp(V_{ni})}{\sum_j \exp(V_{nj})} \tag{6.17}$$

Under the assumption that representative utility is linear in parameters, it can be expressed as:

$$V_{nj} = Z'_{nj}\beta + S'_n\gamma \tag{6.18}$$

where Z'_{nj} and S'_n are vectors of the attributes related to alternative *j* and individual *n*, respectively, and β and γ are the vectors of the coefficients (Lanscar and Louviere, 2008). The choice probability therefore becomes:

$$P_{ni} = \frac{\exp\left(Z'_{nj}\beta + S'_n\gamma\right)}{\sum_j \exp\left(Z'_{nj}\beta + S'_n\gamma\right)} \tag{6.19}$$

Conditional logit models assume the independence of irrelevant alternative (IIA), meaning that the ratio of choice probabilities does not change if other alternatives are added to or removed from the set (Louviere et al., 2000). A test for this assumption was proposed by Hausman and McFadden (1984), which uses the Hausman (1978) test to compare the coefficients of models run on complete and restricted sets of alternatives.

Mixed (or random parameter) logit models

Mixed (or random parameter) logit models (McFadden and Train, 2000) constitute an alternative in situations where IIA is not fulfilled. Mixed logit models relax the IIA assumption, and have additional advantages over multinomial logit models by allowing for random taste variation within the population, removing the assumption of proportionate substitution and appropriately handling panel data (Train, 2009).

In mixed logit models, β is not fixed (as it is in conditional logit) but instead varies over decision makers, and the choice probability is unconditional on the estimated parameters (Train, 2009):

$$P_{ni} = \int \left(\frac{exp(\beta' x_{ni})}{\sum_j \ exp\left(\beta' x_{nj}\right)} \right) f(\beta)\, \delta\beta \tag{6.20}$$

The data from the choice experiment was modelled within STATA using the mixlogit user-written command (Hole, 2007). Following Taylor and Longo (2010), Jacobsen and Thorsen (2010) and McVittie and Moran (2010), all the parameters except cost were allowed to be random. Alternative specific constants were not derived within the model, as the barrage alternatives were unlabelled and so had no utility of themselves beyond that provided by the attributes.

Implicit Prices

The implicit price, *F*, of attribute *z* is the ratio of its coefficient to that of the cost variable, *c* (Alberini et al., 2006; Equation 6.21). The negative of the attribute coefficient is used, to account for the negative sign of the cost coefficient.

$$F_z = -\frac{\hat{\beta}_z}{\hat{\beta}_c} \tag{6.21}$$

Bateman et al. (2002) provide a method by which the standard errors of the marginal prices can be estimated:

$$var\left(\frac{\beta_z}{\beta_c}\right) = \left(\frac{\beta_z}{\beta_c}\right)^2 \left(\frac{var(\beta_z)}{\beta_z^2} + \frac{var(\beta_c)}{\beta_c^2} - \frac{2cov(\beta_z, \beta_c)}{\beta_z \beta_c}\right) \tag{6.22}$$

where the covariance is assumed to be zero as an orthogonal design was used.

6.6 Summary

The outcome of focus group discussions (see Chapter 5) and the best practice described in the literature led to the design of survey instruments that utilised both contingent valuation supported by the Analytic Hierarchy Process (AHP), and a choice experiment. Using these different methods will allow comparisons to be made between the WTP estimates derived using each technique and hence to determine confidence in the WTP obtained. Responses to the AHP, questions on attitudes to energy issues and socio-economic information will improve understanding of the factors that influence to WTP. Questions to identify protest attitudes, and scenarios to determine scope sensitivity were also included in the questionnaire.

A pilot study suggested that the instrument was appropriate and that members of the public would engage with the survey. The main survey was then implemented with the general public at two locations (to assess distance decay effects) and also with marine science experts, so that the effect of specialist knowledge on value could be assessed. The results of the empirical assessments are presented in the following chapter.

7 Results

7.1 Introduction

This chapter presents the results of the empirical research. It is divided into two main sections: the first describes the outcomes of the contingent valuation (CV) and Analytic Hierarchy Process (AHP), and the second presents the result of the choice experiment.

The CV and AHP were carried out in a combined survey instrument with i) members of the public in North Devon and Wellington, Somerset via face-to-face interviews, and ii) academics based in Plymouth through an online survey. Parameters connected to the survey administration (such as interview time and respondent reaction) are reported, and the socio-economic characteristics of the samples populations are presented, as are respondents' attitudes to energy issues. The AHP weights for the different barrage attributes are reported, together with analysis of the differences between the samples and the socio-economic variables which may influence AHP weights. Willingness to pay (WTP) estimates to reduce estuarine mudflat loss are derived, and modelled including a range of socio-economic variables as explanatory factors. Scope sensitivity within WTP is also assessed.

The choice experiment was carried out with members of the public in North Devon, again using face-to-face interviews. The characteristics of the sample population are again presented, and also compared to those of the North Devon respondents who completed the contingent valuation exercise. Conditional and mixed logit models are used to analyse the survey responses, and the implicit prices of the different barrage attributes are calculated. The socio-economic characteristics that were significant within the model and the implicit price of reducing habitat loss are compared to the results of an interval regression model of the contingent valuation data collected from North Devon respondents during the first phase of the survey.

7.2 Phase One: Analytic Hierarchy Process and Contingent Valuation

Survey administration

Face-to-face interviews were carried out with 221 respondents in North Devon and 80 in Wellington. The online survey was completed by 56 marine experts and 62 other academics. The response rate for the online survey was slightly higher for the marine experts (25%) than for the group of other academics (21%). Not all respondents completed all questions, which is reflected in the sample sizes for specific parts of the analysis. In particular, respondents were often unwilling to reveal personal financial information in the face-to-face study. 24% of North Devon respondents and 31% of those interviewed in Wellington either did not know or refused to disclose their household income. Only two respondents from the online groups (both in the expert sample) did not provide information about their income.

The full surveys took between five and 40 minutes to complete, with a mean duration of 11 minutes in Wellington and 19 minutes in North Devon. Only 10% of surveys in Wellington took more than 15 minutes to complete, compared to 51% of those in North Devon. The longer duration for the latter site is not a reflection of the time taken to complete the survey questions, but instead represents the extra time taken by one of the North Devon interviewers (who carried out 40% of the surveys at that site) to record additional general comments that had been made by the respondents during the course of the survey. There was no evidence of a correlation between survey duration and WTP (ρ = -0.0406, p = 0.4983), nor was any discernible interviewer effect on WTP. To test this, the respondents were divided by interviewer, and there was no significant difference in the median WTP values for each interviewer subsample (Kruskal-Wallis $\chi 2$ = 8.168, p = 0.1472).

There did not appear to be any issue with the respondents finding the survey difficult or being annoyed by it; at least 80% of respondents from both sites were judged by the interviewers to have found the survey "very easy" to complete and to have been "not at all annoyed" by it. Only one respondent failed to complete the face-to-face survey, having to stop to deal with childcare.

Description of sample populations

The socio-economic characteristics of the subsamples are described to provide some indication of potential causes of similarity or differences in responses. There were some significant differences in the socio-economic characteristics between the sample groups (Table 7), particularly in their income levels. Respondents in the expert group generally had lower incomes than their counterparts in other academic disciplines, which is perhaps explained by the higher proportion of students in the expert group. The presence of greater numbers of students and research fellows in the expert group also explains some of the differences in age and employment levels.

Differences between the face-to-face and online groups were larger than the differences between the samples within each group. However, higher employment, income and education levels were to be expected, as the online group was selected specifically by profession. Spearman's rank coefficient was used as a preliminary diagnostic to evaluate correlations between variables (as cross-tabulation and evaluation of chi-squared values would be cumbersome with so many variables). The expected positive correlations between income, employment and academic qualifications were apparent (Table 8), and these variables were also positively correlated with membership of a conservation group and monthly household electricity bill. Monthly bills, age group and frequency of visits to the Taw Torridge were also all correlated with size of household.

Overall, the statistical results are consistent with expectations of underlying relationships and characteristics of the respective samples.

Table 7. Key statistics describing the sample populations, and the level of significance in differences between them.

	Face-to-face interviews			Online surveys		
	North Devon	Wellington	χ^2	Marine experts	Other academics	χ^2
Number of respondents	221	80		56	62	
% of respondents who have visited the site at least once per year in the past 5years	n/a	75.0	n/a	17.9	19.4	3.66
% of male respondents	50.2	51.3	0.18	52.7	59.7	0.57
Median age group category (yrs)	35 – 44	35 – 44	12.21*	35 – 44	45 – 54	21.26**
% of respondents who are:			10.45			14.47**
Employed	50.7	64.5		80.0	98.4	
Retired	28.3	12.7		3.6	1.6	
Students	6.4	5.1		16.4	0	
Otherwise not working	14.6	17.7		0	0	
Median annual household income category (£000s)	25 – 35	15 – 25	10.21*	35 – 45	55 – 65	15.49*
Median monthly electricity bill category (£)	31 – 40	41 – 50	14.45*	41 – 50	41 – 50	2.78
% of respondents with degree	29.4	25.9	2.43	94.3	100.0	3.43
Mean number in household	2.8	2.8		2.4	2.6	
% of respondents who are members of a conservation group	13.6	11.3	0.33	40.0	28	0.54

Significance of χ^2 statistic: ** < 1%, * < 5%

Table 8. Correlation matrix of ρ values for socio-economic variables

	Frequency of visits to the Taw Torridge	Gender	Age group	Size of household	Employed	Income	Highest academic qualification	Monthly electricity bill
Gender	0.072							
Age group	-0.158	0.086						
Size of household	0.219*	-0.068	-0.398**					
Employed	-0.114	0.028	-0.262**	0.176**				
Income	-0.135	0.076	0.077	0.123*	0.442**			
Highest academic qualification	-0.168	-0.068	-0.087	-0.083	0.341**	0.493**		
Monthly electricity bill	-0.002	-0.039	0.001	0.315**	0.180**	0.284**	0.217**	
Member of conservation group	-0.004	-0.031	0.031	0.011	0.109*	0.204**	0.243**	0.104

Significance of ρ statistic: ** < 1%, * < 5%

Attitude to energy issues

Respondents' attitudes to energy issues are important because they may influence their acceptance of the scenarios and may also be a potential motivator for WTP. The majority of respondents agreed or strongly agreed with each of the statements on energy issues (Figure 22, Table 9). There were no significant differences in attitudes to energy issues between the academic groups, and trends were also broadly similar between the North Devon and Wellington sites. North Devon respondents were, however, significantly more likely to agree/strongly agree that climate change is a real problem now compared to those in Wellington, but were less likely to strongly agree that the UK should rely less on imported fuel, even though this could cause an increase in fuel bills.

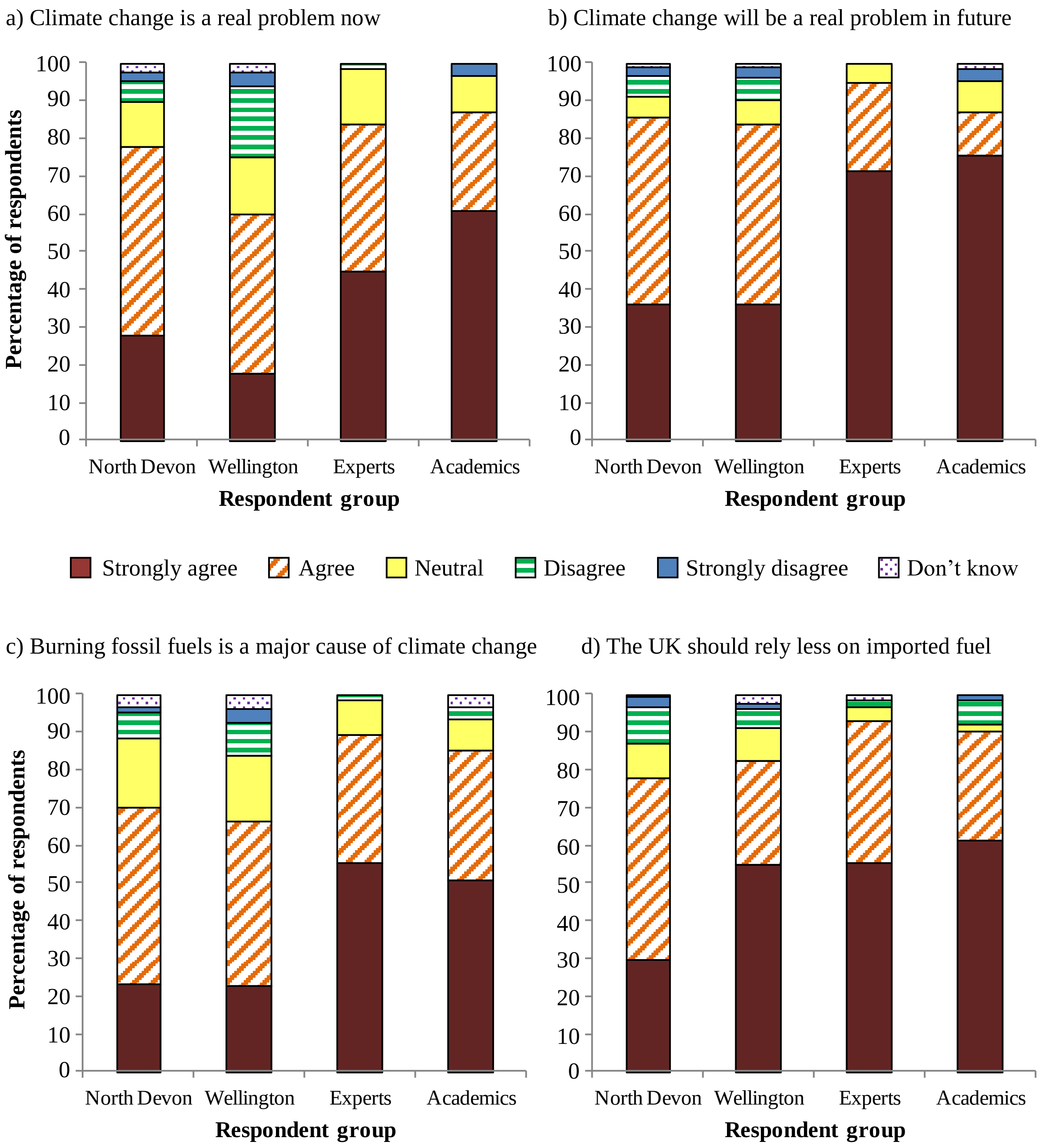

Figure 22. Levels of agreement with statements about climate change and energy security

Table 9. Key statistics describing the attitude towards energy issues of respondents in the sample groups

	Face-to-face interviews			Online surveys		
	North Devon	Wellington	χ^2	Marine experts	Other academics	χ^2
Number of respondents	221	80		56	62	
Percentage of respondents who agree/strongly agree with the statement:						
Climate change is a real problem now	77.8	60.0	14.68**	83.9	86.9	6.35
Climate change will be a real problem in the future	85.5	83.8	0.19	94.6	86.9	4.59
Burning fossil fuels is a major cause of climate change	70.1	66.3	1.36	89.3	85.2	3.02
The UK should rely less on imported fuel, even if this means electricity bills go up	77.8	82.5	18.72**	92.9	90.3	3.67
Percentage of respondents who are not at all/not very well informed about tidal barrages	76.5	72.5	0.90	32.1	50.0	5.32
Percentage of respondents who generate at least some of their own electricity	8.2	6.3	0.09	5.5	9.8	0.59
Percentage of respondents who agree/strongly agree with the statement:						
Building wind farms would be better than building barrages, even if this costs me more	23.6	38.2	7.80	31.5	27.1	4.02
Building nuclear power stations would be better than barrages, even if this is costs me more	12.4	15.4	1.68	20.0	23.0	1.70

Significance of χ^2 statistic: ** < 1%, * < 5%

Respondents were also asked how they felt about tidal barrages in relation to two other non-fossil fuel energy sources (Figure 23). There was evidence of strong opposition to nuclear energy as an alternative to barrages: 70-71% of respondents in both North Devon and Wellington and more than half of the experts/other academics disagreed or strongly disagreed with the statement “Building more nuclear power station would be better than building tidal barrages, even if this is more costly to me”. Responses to a similar question on wind energy were more equivocal, particularly from those in the expert/other academics groups (Figure 23) of whom 43% of experts and 60% of the other academics neither agreed nor disagreed with the statement “Building more wind farms would be better than building tidal barrages, even if this costs me more money”. It should also be noted that knowledge of tidal barrages was particularly low in the North Devon and Wellington samples (Figure 24). Therefore, these responses potentially reflect participants’ general attitude to wind or nuclear power as opposed to a considered comparison with barrages specifically.

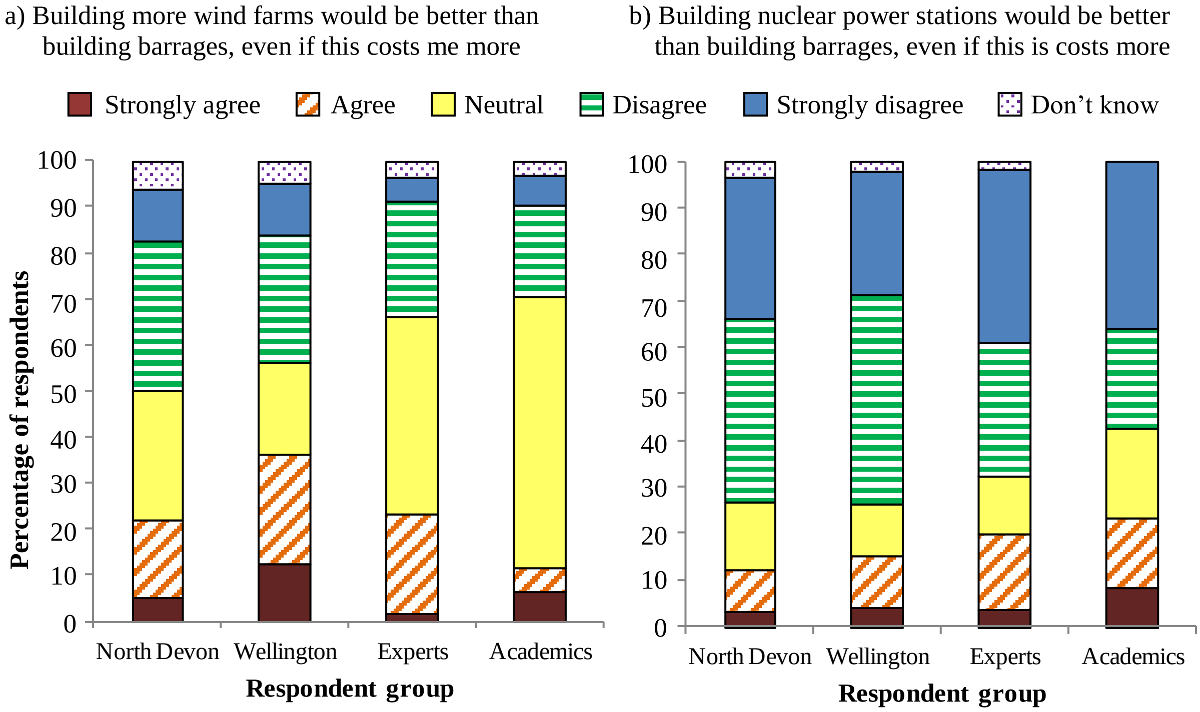

Figure 23. Levels of agreement with statements that wind energy or nuclear power would be preferable to tidal barrages

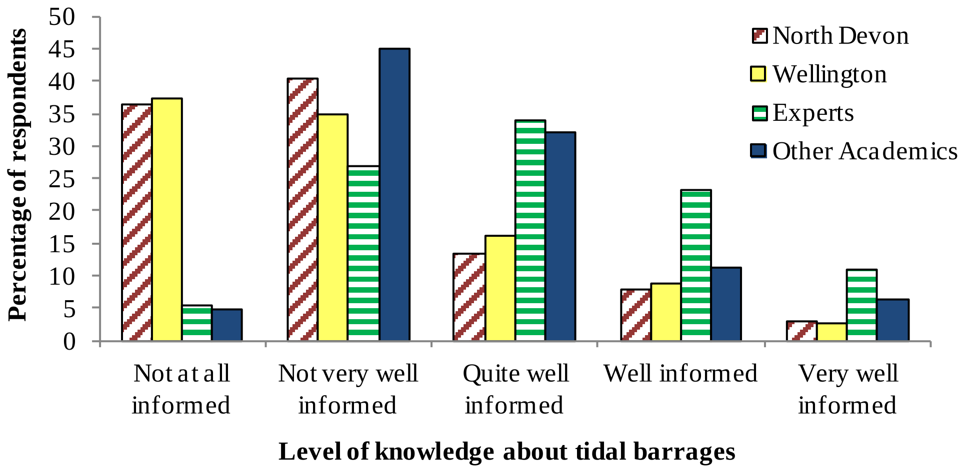

Figure 24. Level of knowledge about tidal barrages amongst respondents from the subsamples

The results above also suggest that attitudes differ between those undertaking the face-to-face survey (North Devon and Wellington) and completing the online questionnaire (experts and other academics). For example, members of the two academic groups had higher levels of agreement with statements that climate change was a real problem and that fossil fuels were an important cause than members of the public in North Devon and Wellington. The underlying socio-economic characteristics of the sample populations were different (Table 10), and it may be these factors that generate the disparity in attitudes.

This implied link between education and opinions was supported by a significant correlation between level of academic attainment and agreement with statements related to climate change. There was no evidence that attitudes to climate change were motivating respondents to generate their own electricity, but electricity generation was significantly correlated with income, suggesting that affordability was the main control on respondent's choice to install microgeneration systems. Older respondents were more likely to agree with the statement that the UK should rely less on imported fuel. Men and respondents without dependents were more likely to prefer nuclear power over tidal barrages, while respondents with higher level of education, younger people, those in employment and those with dependents living at home were more likely to prefer wind power to tidal barrages. There was evidence of a correlation between respondents' knowledge of tidal barrages and their level of education, and also their gender, with men more likely to say that they were better informed about barrages.

Table 10. Correlation matrix of ρ values for variables describing attitudes to energy issues and socio-economic parameters

	Climate change is a problem now	Climate change will be a problem in future	Fossil fuels are a major cause of climate change	The UK should rely less on imported fuel	Wind energy is preferable to tidal barrages	Nuclear energy is preferable to tidal barrages	Level of knowledge about tidal barrages	Generates own electricity
Level of knowledge about tidal barrages	0.05	0.08	0.17**	0.19**	-0.07	0.12*		
Generates own electricity	0.01	0.00	0.07	0.02	-0.09	0.05	0.11*	
Gender	-0.04	-0.05	0.03	0.09	-0.04	0.16**	0.28**	0.04
Age group	-0.04	-0.02	-0.05	0.15**	-0.29**	0.09	0.27**	0.05
Size of household	-0.02	-0.03	0.04	-0.08	0.16**	-0.12*	-0.23**	0.04
Employed	0.07	0.07	0.13**	0.04	0.15**	-0.02	0.06	0.00
Income	0.16**	0.17**	0.20**	0.09	-0.05	0.04	0.25**	0.14*
Highest academic qualification	0.24**	0.31**	0.28**	0.18**	0.12*	0.01	0.23**	-0.01
Member of conservation group	0.01	0.05	0.02	0.01	-0.03	-0.01	-0.05	-0.02

Significance of ρ statistic: ** < 1%, * < 5%

Recreational use of the coastal environment

North Devon respondents were more likely to participate in coastal recreational activities than their Wellington counterparts (Table 11). This is probably a reflection of the increased opportunities available in North Devon given its proximity to the estuary and the coast. Walking or cycling along coastal or river paths was a particularly popular activity, more so than watersports, which would suggest that a majority of respondents tend to restrict their use of these environments to the coastal margin. Birdwatching was also particularly popular amongst North Devon respondents, although this describes enjoyment of birdlife in general as opposed to specific visits to observe estuary birds.

Table 11. The percentage of respondents in each of the sample groups who take part in particular recreational activities at least once per year.

	Face-to-face interviews			Online surveys		
	North Devon	Wellington	χ^2	Marine experts	Other academics	χ^2
Number of respondents	221	80		56	62	
Watersports	37.3	21.3	7.34	87.3	58.3	13.40**
Walking/cycling on coastal/river paths	87.8	61.3	58.68**	94.5	95.2	3.90
Birdwatching	53.6	16.3	42.06**	37.0	31.0	1.10
Recreational angling/crabbing	25.0	21.3	0.47	37.0	8.5	14.03**

Significance of χ^2 statistic: ** < 1%, * < 5%

Participation in one recreational activity was often an indicator of participation in other types of coastal recreation (Table 12). Certain expected socio-economic trends were apparent: older people were less likely to take part in watersports but more likely to enjoy birdwatching, and there was a correlation between birdwatching and membership of a conservation group. Also, the trend for participation in watersports showed an increase with increasing income, which perhaps explains higher uptake rates amongst the academic groups, whose average household income exceeds that of the North Devon and Wellington residents.

Table 12. Correlation matrix of ρ values for variables describing levels of participation in coastal recreational activities and socio-economic parameters

	Frequency of participation in:				
	watersports	walking or cycling on coastal or river paths	bird-watching	wildfowling	recreational angling or crabbing
Walking or cycling on coastal or river paths	0.334**				
Birdwatching	0.108*	0.437**			
Wildfowling	0.095	0.037	0.014		
Recreational angling or crabbing	0.247**	0.146**	0.117*	0.236**	
Frequency of visits to the Taw Torridge	-0.027	0.026	-0.004	0.030	0.068
Gender	0.006	-0.012	-0.071	0.051	0.044
Age group	-0.168**	-0.076	0.233**	-0.072	-0.101*
Size of household	0.113*	0.077	-0.047	0.010	0.097*
Employed	0.264**	0.021	-0.183**	0.028	0.056
Income	0.324**	0.089	-0.006	-0.005	-0.025
Highest academic qualification	0.368**	0.063	0.021	-0.038	-0.131**
Member of conservation group	0.266**	0.058	0.176**	-0.022	0.114*

Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process was used to identify the relative importance to the respondents of four different barrage attributes, and hence to gain insight into their pro-environmental attitude. Considering the sample as a whole (n=412), mudflat loss and additional flood protection were most important to respondents, and were given significantly higher AHP weights than cost and watersports gain (Figure 25, Table 13).

At the subsample level, the AHP weights for flood protection, watersports gain, and loss of coastal mudflat were significantly different between the North Devon and Wellington sample sites (Figure 26, Table 14). For North Devon respondents, the importance of mudflat loss was not significantly different from that of flood protection, but both were significantly higher than additional cost (Table 15). In Wellington, the weight for flood protection was significantly higher than that of mudflat loss and additional cost, which were equally weighted. The weight for watersports gain was significantly lower than those for other attributes at both sites.

Comparing the marine experts and the group of other academics, the AHP weights were not significantly different between the two groups, or between additional flood protection and cost (Figure 27, Table 16, Table 17). Mudflat loss was given a significantly higher weighting than flood protection and additional cost, while the weighting for watersports gain was significantly lower than those for the other attributes.

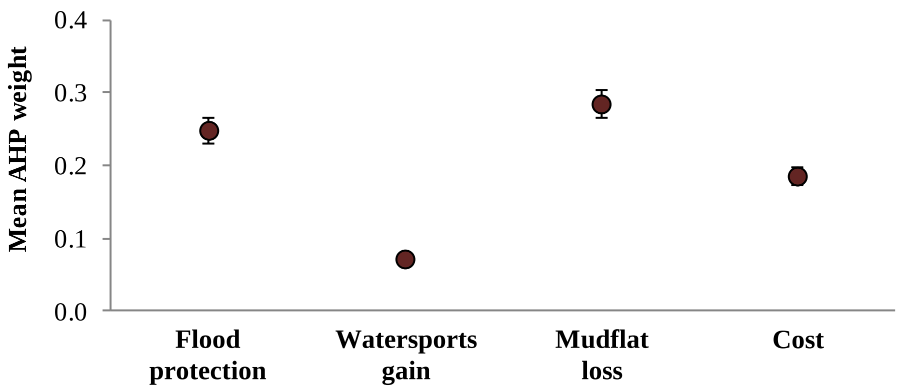

Figure 25. Geometric mean and 95% confidence interval for the AHP weights for the barrage attributes (n=412).

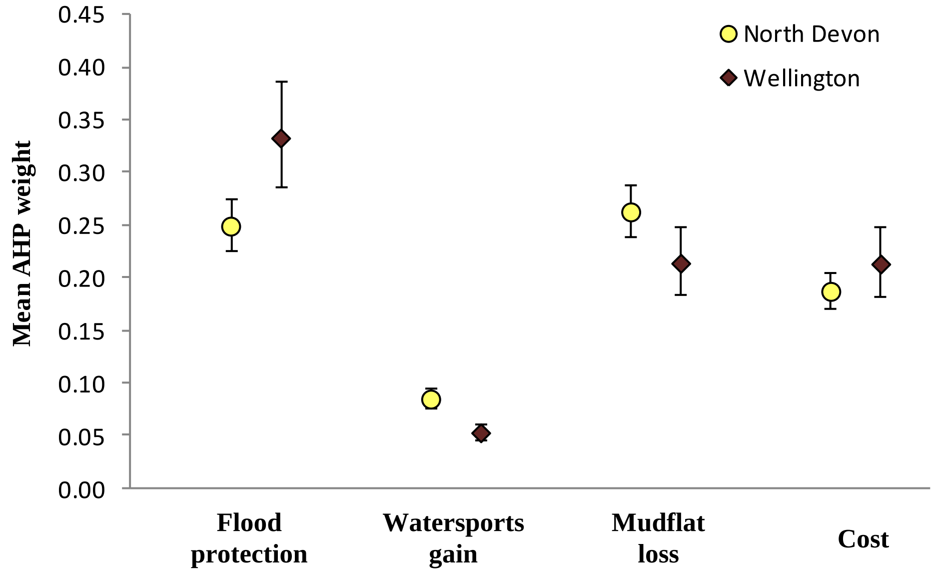

Figure 26. Geometric mean and 95% confidence interval for the AHP ratings from the North Devon (n=220) and Wellington (n=80) samples.

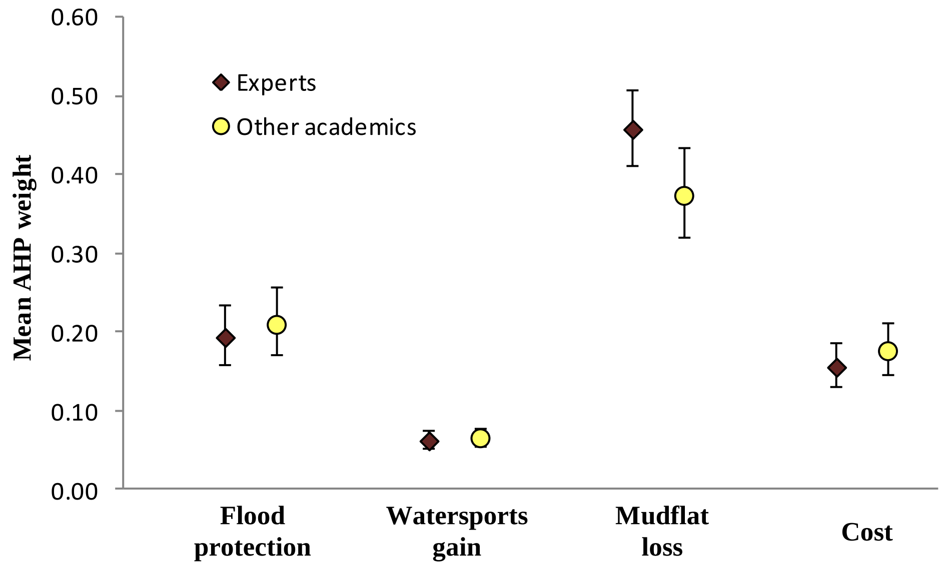

Figure 27. Geometric mean and 95% confidence interval for the AHP ratings from the expert and other academics samples

Table 13. Results of Wilcoxon signed-ranks tests to assess the hypothesis that there is no difference between the attribute weights (n=412)

Attribute pairs	z	p
Flood protection vs watersports gain	14.292	0.0000
Flood protection vs mudflat loss	-1.759	0.0786
Flood protection vs additional cost	5.547	0.0000
Watersports gain vs mudflat loss	-15.011	0.0000
Watersports gain vs additional cost	-12.141	0.0000
Mudflat loss vs additional cost	7.224	0.0000

Table 14. Results of Mann-Whitney tests to assess the hypothesis that attribute weights are the same for both the North Devon (n=220) and Wellington (n=80) samples

Attribute	z	p
Additional flood protection	-3.269	0.0011
Additional time for watersports	4.366	0.0000
Loss of coastal mudflat	2.459	0.0139
Additional cost of electricity	-1.261	0.2073

Table 15. Results of Wilcoxon signed-ranks tests to assess the hypothesis that the attribute weights are the same within each survey site

Attribute pairs	North Devon (n=220)		Wellington (n=80)	
	z	p	z	p
Flood protection vs watersports gain	9.329	0.0000	7.310	0.0000
Flood protection vs mudflat loss	-0.377	0.7062	3.756	0.0002
Flood protection vs additional cost	3.928	0.0001	3.250	0.0012
Watersports gain vs mudflat loss	-9.548	0.0000	-7.027	0.0000
Watersports gain vs additional cost	-7.416	0.0000	-6.933	0.0000
Mudflat loss vs additional cost	4.337	0.0000	-0.014	0.9885

Table 16. Results of Mann-Whitney tests to assess the hypothesis that attribute weights are the same for both the experts (n=54) and other academics (n=58) samples

Attribute	z	p
Additional flood protection	-0.714	0.4754
Additional time for watersports	-0.722	0.4705
Loss of coastal mudflat	1.538	0.1241
Additional cost of electricity	-0.915	0.3602

Table 17. Results of Wilcoxon signed-ranks tests to assess the hypothesis that the attribute weights are the same within each sample group

Attribute pairs	Experts		Other academics	
	z	p	z	p
Flood protection vs watersports gain	5.146	0.0000	5.920	0.0000
Flood protection vs mudflat loss	-4.939	0.0000	-3.129	0.0018
Flood protection vs additional cost	1.834	0.0666	1.460	0.1444
Watersports gain vs mudflat loss	-6.368	0.0000	-6.403	0.0000
Watersports gain vs additional cost	-4.396	0.0000	-5.273	0.0000
Mudflat loss vs additional cost	5.524	0.0000	4.196	0.0000

Comparison between surveys

Mudflat loss was rated as the most important barrage attribute by respondents in both the academic subgroups and from North Devon, yet was lower for the latter group despite their residing closest to the Taw Torridge. However, as noted above, the socio-economic characteristics of the subgroups were different, and so a better comparison can be made by considering only those from the North Devon sample whose education profile is similar to that of the academic groups. The Wellington subsample was excluded from this comparison because too few respondents had the relevant level of education. This new comparison confirmed differences in the relative magnitude of the attribute weights (Figure 28). The weight given to mudflat loss by this North Devon group was significantly lower than that of the marine experts (Mann Whitney z= -3.651, p= 0.0003), while the North Devon respondents gave a significantly higher weighting to watersports than either the expert or other academics groups (Kruskal-Wallis χ^2= 8.878, p= 0.012).

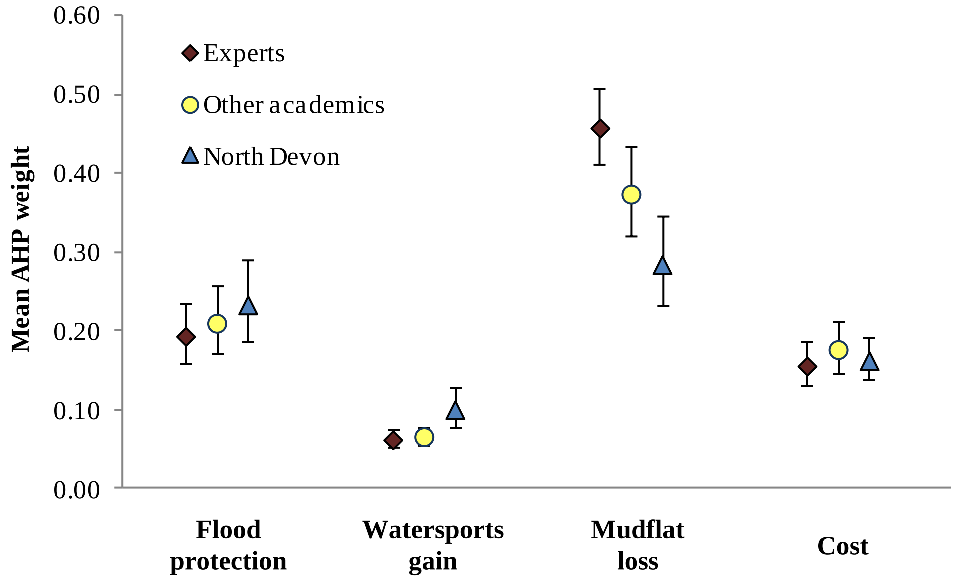

Figure 28. Geometric mean and 95% confidence interval for the AHP ratings from the experts (n=54) and other academics (n=58) samples and from a subsample of North Devon respondents with a similar educational profile (n=55)

Socio-economic factors influencing AHP choices

Individual AHP weights were correlated with each other because increasing the weighting of one decreases that for another, due to the nature of the technique. This lack of independence makes it difficult to model the factors that affect AHP weights. Linear regression was attempted nonetheless, to provide an indication of which socio-economic variables might be influencing AHP choices. The models are generally weak, and the regression for the cost AHP was not significant (Table 18). As would be expected, much of the variation in a particular AHP weight is better explained by the AHP weights of the other attributes. For example, adding the AHP weights for watersports gain and flood protection as explanatory variables increases the R^2 value for the mudflat loss model from 0.14 to 0.45. The variation in the number of observations is due to missing values in one of the attributes.

Limited as they are, the models produced results that conform to expectations. The regression suggests that the AHP weight for mudflat loss is higher amongst those who walk or cycle on coastal paths or birdwatch at least once per month (Table 19). The survey mode was also a significant predictor of mudflat AHP weight, with those completing the online survey more likely to give a higher weight. Three variables were also significant in predicting the AHP weight for watersports gain: those living in North Devon, men and those who take part in watersports at least once per month were all more likely to give a higher weight. Past experience of domestic flooding was a significant predictor of increasing AHP weight for additional flood protection. Those who regularly participate in watersports were more likely to give lower AHP weight for flood protection. This is most likely to reflect the tradeoff between watersports and flood protection AHP weights, with watersports enthusiasts likely to increase the former at the expense of the latter.

Table 18. Descriptive statistics for linear regression models using robust standard errors, for the four barrage attributes

	Mudflat loss	**Watersports gain**	**Flood protection**	**Cost**
n	407	408	110	298
F	24.05	9.30	6.92	1.22
p	<0.0001	<0.0001	0.0015	0.2332
R^2	0.1434	0.0984	0.0895	0.0733
Root MSE	0.1838	0.1032	0.1513	0.15982

Table 19. The variables that were significant in a linear regression model for predicting the AHP weights for mudflat loss, watersports gain and flood protection.

Mudflat loss			**Watersports gain**			**Flood protection**		
	Coef.	t		Coef.	t		Coef.	t
MODE	0.156	-7.38**	*LOCAL*	0.051	5.05**	*HOUSEFLOOD*	0.090	2.00*
WALK/CYCLE	0.047	2.42*	*GENDER*	0.028	2.76**	*SPORT*	-0.72	-2.52*
BIRD	0.049	2.30*	*SPORT*	0.044	2.96**			
_CONS	0.414	18.09**	*_CONS*	0.049	4.92**	*_CONS*	0.276	12.64**

Significance of t-statistic: ** < 1%, * < 5%

Key to variable abbreviations

Variable	**Description**
BIRD	1= goes birdwatching at least once a month; 0 otherwise
GENDER	1= male; 0 female
HOUSEFLOOD	1 = past experience of domestic flooding; 0 otherwise
LOCAL	1 = lives within 5 miles of the Taw Torridge estuary; 0 otherwise
MODE	1 = face-to-face interview; 0 = online survey
SPORT	1= takes part in watersports at least once a month; 0 otherwise
WALK/CYCLE	1= walks/cycles on coastal/river paths at least once a month; 0 otherwise

Consistency Ratios

Consistency ratios (CRs) are used to relate the results of the respondent's preference matrix to those of a random matrix of the same dimensions, and it has been suggested that these should not exceed 0.1 (Saaty, 2008). Interpretation of CRs is slightly counter-intuitive, as a higher CR indicates lower choice consistency. In this study, the consistency ratios were generally high. No more than 36% of any of the sample groups returned a CR of less than 0.1, and for one subsample (Wellington) less than half of the sample had a CR of less than 0.2 (Figure 29). The CRs for the marine expert and other academics groups both closely matched that of the North Devon sample (Kruskal-Wallis χ^2= 1.433, p= 0.4886), while Wellington respondents had significantly higher CRs compared to respondents from North Devon (Mann-Whitney z= -2.954, p= 0.003).

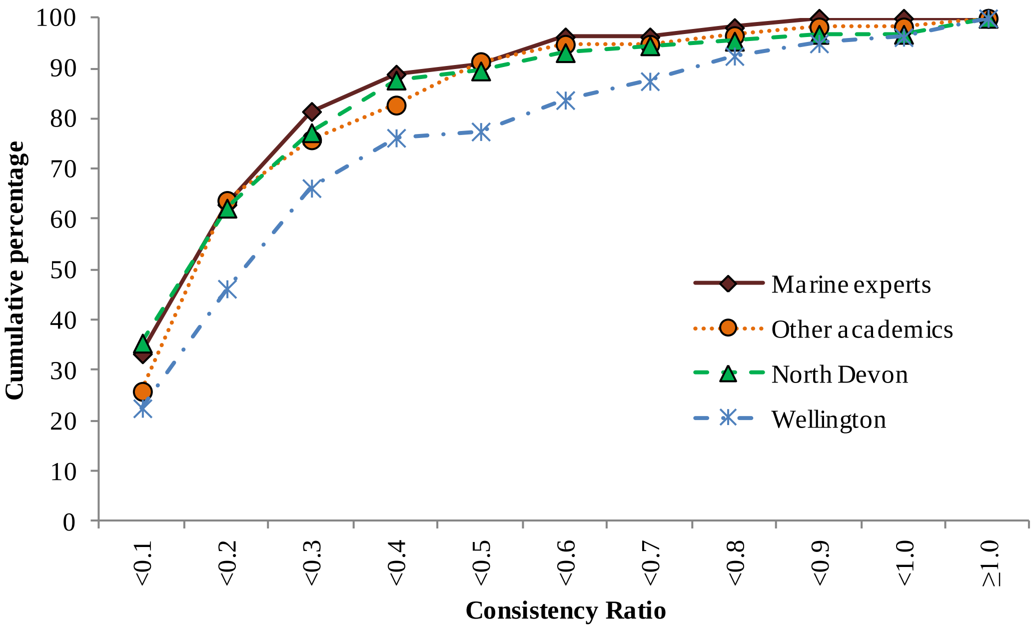

Figure 29. The cumulative frequency of the AHP consistency ratio for each subsample from the face to face and online surveys

Contingent Valuation

Summary WTP statistics

WTP was collected using a payment card, so the respondent's exact WTP is not known. The value on the payment card chosen by the respondent represents the lower bound of WTP. His actual WTP may exceed this value, but will be less than the next highest amount shown on the card. The highest value of WTP listed on the payment card was £200, but respondents were also given the opportunity to choose "more" on the payment card, and subsequently to state the exact value of their WTP (the only instance when it was possible for exact WTP to be stated).

Of the 419 respondents completing the survey, 11 (2.6%) did not know how much they were willing to pay or else refused to answer the question, reducing the total sample size to 408. The

WTP chosen in the survey (Figure 30) showed a cluster of respondents whose WTP was £0 as well as prominent peaks at stated values that represent round figures (particularly £5, £10, £50). The possibility that the zero bids included protest responses was explored following preliminary modelling, and is discussed in a later section below. From the first contingent scenario, the mean (median) WTP to reduce the loss of intertidal habitat by 70ha was £26.17 (£11) per year (Table 20). This was calculated using the mid-point of the interval between the value chosen on the payment card and the next highest value shown. The WTP of the experts and other academics completing the online survey was significantly higher than that of the members of the public from North Devon and Wellington (Table 21), but socio-economic factors, including income, also differed significantly between the groups (Table 7).

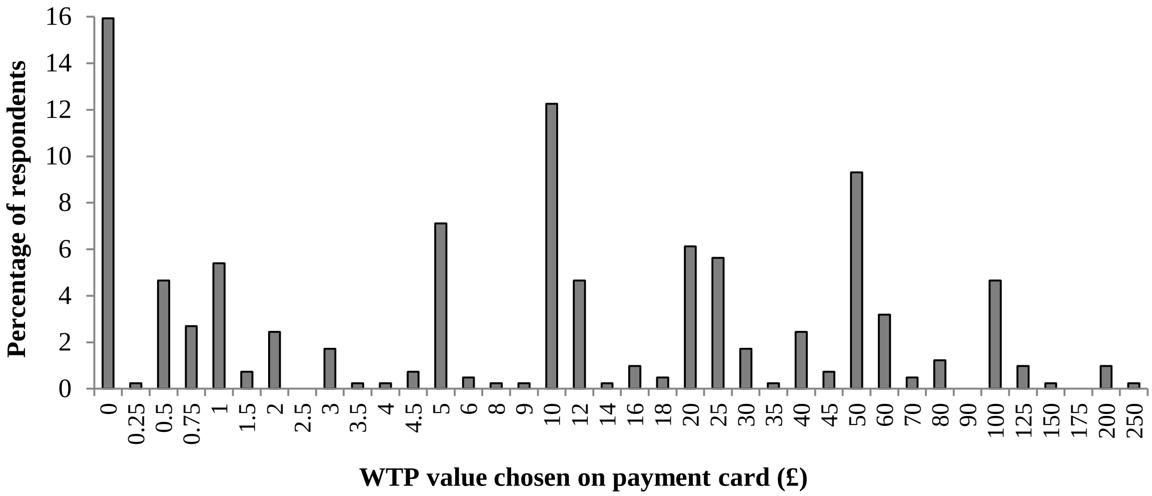

Figure 30. The distribution of stated WTP values

Table 20. Summary statistics for the WTP to reduce mudflat loss by 70ha

	Full sample	North Devon	Wellington	Experts	Other academics
Total number of respondents	419	221	80	56	62
Don’t know/missing WTP	11	6	4	0	1
Sample size for WTP analysis	408	215	76	56	61
Median annual household income category (£000)	25 – 35	25 – 35	15 – 25	35 – 45	55 – 65
Arithmetic Mean WTP (£)	26.17	24.11	21.98	28.26	36.75
standard error	1.87	2.81	3.55	3.81	4.96
95% confidence interval	22.5; 29.8	18.6; 29.7	14.9; 29.0	20.6; 35.9	26.8; 46.7
Median WTP (£)	11	5.50	13	22.5	25
Minimum (£)	0	0	0	0	0
Maximum (£)	250	250	200	137.5	162.5

Table 21. Results of Mann-Whitney tests to assess the hypothesis that WTP is the same across the samples

Sample groups		z	p
North Devon	Wellington	-1.287	0.1981
North Devon	Experts	-3.221	0.0013
North Devon	Other academics	-16.793	<0.001
Wellington	Experts	-1.7789	0.0754
Wellington	Other academics	-2.322	0.0202
Experts	Other academics	-0.673	0.5012

Econometric modelling

Socio-economic data and information about attitudes to energy issues were collected during the survey, as these may influence WTP. Several of the variables describing socio-economic and attitudinal parameters were correlated with each other, particularly income, education and employment levels. Income is a well-known constraint on an individual's ability to maximise his/her utility (Hanley et al., 1997), so the income variable was retained, and the correlated explanatory variables excluded from the model (although models substituting these alternative variables were later explored, as detailed below). The correlations between the AHP weights for the four barrage attributes (mudflat loss, flood protection, watersports gain, and cost) were also significant, and were particularly strong between mudflat loss and flood protection ($\rho = 0.52$) and mudflat loss and cost ($\rho = 0.41$).

The AHP weight for mudflat loss was used as an explanatory variable in the model, as this was expected to be most salient as a predictor of the respondent's level of concern for the affected intertidal habitat. Using the AHP weight for mudflat loss also required the omission of the dummy variables indicating whether respondents regularly went birdwatching or walking/cycling on coastal paths, because these variables were significant in determining AHP weights for mudflat loss (Table 19). These dummies were for general participation in the activities, not for use of the Taw Torridge specifically.

A further group of correlated variables were those related to opinions on energy issues. A dummy variable representing "strong agreement" (Likert scale 5/5) with the statement "Climate change will be a real problem in the future" was used as the single predictor to represent a respondent's attitude to climate change and energy issues, as this returned the highest t-statistic when individual dummies of the different energy variables were tested in regression analysis. After exclusion of all the correlated variables, 14 variables (Table 22) were used to model WTP, initially with OLS regression using the mid-point of the interval between the value chosen on the payment card and the next highest value shown (Table 23). Repeating the model but substituting alternative variables where correlations existed resulted in lower model R^2 values in all cases and reduced significance of certain parameters (Table 24), suggesting that the most appropriate variables had already been selected.

Table 22. The variables used in constructing the econometric models for the contingent valuation

Variable	Type	Description	Predicted sign
INCOME	Interval	Income (categories are pooled below £15,000 and above £65,000 due to low respondent numbers in those categories)	+
MUDAHP	continuous	Analytical Hierarchy Process weight for mudflat loss	+
LOCAL	Dummy	1 = lives within 5 miles of the Taw Torridge estuary	+
MODE	Dummy	1 = face-to-face interview; 0 = online survey	+
EXPERT	Dummy	1 = has specialist marine science knowledge	+
CLIMATE_ FUTURE	Dummy	1= strongly agrees (Likert 5/5) that climate change will be a problem in the future	+
KNOW_ TIDAL	Dummy	1 = at least quite well informed about tidal barrages	+
OWNELECT	Dummy	1= generates at least some household electricity with e.g. solar panels	-
GENDER	Dummy	0= female; 1= male	-
AGE	Interval	Age group	+
SIZEHHOLD	Dummy	1 = household size exceeds 2	-
NATUREGRP	Dummy	1= member of nature/conservation group	+
SPORT	Dummy	1= takes part in watersports at least once a month	-
ANGLING	Dummy	1= goes angling or crabbing at least once a month	+

Table 23. The complete output of the OLS regression on WTP to reduce mudflat loss, using interval mid-point data. Descriptions of the variables are provided in Table 22.

Source	SS	df	MS
Model	72941	14	5210
Residual	413318	295	1401
Total	486260	309	1573

n	=	310
F (14, 295)	=	3.72
p	=	0.0000
R^2	=	0.1500
Adj R^2	=	0.1097
Root MSE	=	37.431

	Coef.		t	95% Conf. Interval	
INCOME	3.086	(1.334)	2.31*	0.461	5.710
MUDAHP	45.380	(12.025)	3.77**	21.715	69.045
LOCAL	3.752	(6.253)	0.60	-8.555	16.058
MODE	4.024	(9.225)	0.44	-14.131	22.179
EXPERT	-7.891	(8.100)	-0.97	-23.832	8.050
CLIMATE_FUTURE	17.679	(4.539)	3.89**	8.745	26.613
KNOW_TIDAL	6.356	(5.212)	1.22	-3.901	16.614
OWNELECT	-5.240	(9.298)	-0.56	-23.539	13.059
GENDER	-10.072	(4.545)	-2.22*	-19.017	-1.127
AGE	0.730	(1.706)	0.43	-2.628	4.087
SIZEHHOLD	-4.444	(4.996)	-0.89	-14.276	5.388
NATUREGRP	-4.538	(5.601)	-0.81	-15.560	6.485
SPORT	-4.288	(5.258)	-0.82	-14.637	6.060
ANGLING	0.620	(6.935)	0.09	-13.028	14.268
_CONS	-6.278	(13.032)	-0.48	-31.926	19.370

Standard errors of the coefficients are given in brackets.
Significance of t-statistic: ** < 1%, * < 5%

Table 24. R^2 and t values for the OLS model of WTP to reduce mudflat loss when run using alternative variables, which are correlated with parameters used in the original model (as shown in Table 23)

Variable	**Type**	**Description**	**Model R^2**	**t**
Preferred variable				
INCOME	Interval	Income (categories are pooled below £15,000 and above £65,000 due to low numbers)	0.1500	2.31*
Alternative variables				
DEGREE	Dummy	1 = educated to degree level	0.1235	1.44
ALEVEL	Dummy	1 = educated to A-level	0.1250	1.64
GCSE	Dummy	1 = educated to GCSE level	0.1185	0.13
Preferred variable				
MUDAHP	continuous	Analytical Hierarchy Process weight for mudflat loss	0.1500	3.77**
Alternative variables				
FLOODAHP	continuous	Analytical Hierarchy Process weight for flood protection	0.1138	-1.27
SPORTAHP	continuous	Analytical Hierarchy Process weight for watersports gain	0.1092	0.25
COSTAHP	continuous	Analytical Hierarchy Process weight for additional cost of electricity	0.1354	-3.00**
WALK	Dummy	1= walks/cycles on coastal/river paths at least once a month	0.1057	0.40
BIRD	Dummy	1= birdwatches at least once a month	0.1119	1.41
Preferred variable				
CLIMATE_ FUTURE	Dummy	1= strongly agrees (Likert 5/5) that climate change will be a problem in the future	0.1500	3.89**
Alternative variables				
CLIMATE_ NOW (+)	Dummy	1= strongly agrees (Likert 5/5) that climate change is a problem now	0.1441	3.68**
CLIMATE_ NOW (-)	Dummy	1= disagrees or strongly disagrees (Likert 1-2/5) that climate change is a problem now	0.1062	-0.68
CLIMATE_ FUTURE (-)	dummy	1= disagrees or strongly disagrees (Likert 1-2/5) that climate change will be a problem in the future	0.1127	-1.46
CLIMATE_ FFCAUSE (+)	dummy	1= strongly agrees (Likert 5/5) that fossil fuels are a major cause of climate change	0.1204	2.27*
CLIMATE_ FFCAUSE (-)	dummy	1= disagrees or strongly disagrees (Likert 1-2/5) that fossil fuels are a major cause of climate change	0.1132	-1.67
IMPORTS (+)	dummy	1= strongly agrees (Likert 5/5) that the UK should rely less on fuel imports	0.1199	2.09*
IMPORTS (-)	dummy	1= disagrees or strongly disagrees (Likert 1-2/5) that the UK should rely less on fuel imports	0.1112	-1.18
WIND (+)	dummy	1= agrees or strongly agrees (Likert 4-5/5) that wind power is preferable to barrages	0.1063	1.31
WIND (-)	dummy	1= disagrees or strongly disagrees (Likert 1-2/5) wind power is preferable to barrages	0.1010	-0.25
NUCLEAR (+)	dummy	1= agrees or strongly agrees (Likert 4-5/5) that nuclear power is preferable to barrages	0.1049	0.05
NUCLEAR (-)	dummy	1= disagrees or strongly disagrees (Likert 1-2/5) that nuclear power is preferable to barrages	0.1049	0.04

Significance of t-statistic: ** < 1%, * < 5%

A larger suite of diagnostic tests is available for simple OLS regression compared to alternative models, the results of which can increase confidence in the model outputs. These tests showed that there were no significant issues of multicollinearity, as the variance inflation factors were less than 4 (indeed, less than 2 for 12 of the 14 variables). There were also no significant model specification errors (Ramsey RESET test, F = 1.54, p = 0.204; specification link test $\hat{y}^2$, t = 0.34, p = 0.735).

However, a simple OLS model is inappropriate for wider data interpretation because the residuals were not normal (z = 8.723, p < 0.001) and were heteroskedastic (Breusch-Pagan/Cook-Weisberg test, χ^2 = 51.79, p < 0.001). Therefore, the p-values associated with the *t*-and F-tests may be invalid (Dougherty, 2011), and, while the OLS regression remains linear and unbiased, it is no longer the most efficient model (Gujarati, 1995).

Other models were considered to improve normality and homoskedasticity (Table 25), which were run using the initial list of variables (as given in Table 22). The preferred econometric model was to use interval regression on $\log_e$-transformed data with robust standard errors and allowing for left-censoring of the data (Model 5 in Table 25). Interval regression is the most appropriate approach for interval data (Cameron and Huppert, 1989), and the fit of linear and $\log_e$-transformed data was compared using the Box-Cox method (Dougherty, 2011), which confirmed that the transformed data proved a better fit (RSS linear = 2,933; RSS $\log_e$-transformed = 178).

The relationships found in the preferred model appear very robust, as the same four explanatory variables were the only significant parameters in any model. Thus, the model predicts that WTP increases a) with income; b) with the mudflat loss weight given by the respondent in an Analytic Hierarchy Process; c) if the respondent strongly agrees (Likert scale 5/5) that climate change will be a problem in the future; and d) if the respondent is female. Also worthy of note are some of the variables which were not significant predictors of WTP. The survey mode (face-to-face vs online); whether a respondent lives near the Taw Torridge; and level of expert knowledge about the marine environment did not appear to influence WTP.

Table 25. The regression coefficients (coef.) and associated t- or z-statistic for each of the five econometric models tested (n=310). Descriptions of the variables are provided in Table 22.

	Model 1: OLS, robust S.E.		**Model 2: WLS**		**Model 3: OLS**		**Model 4: Tobit**		**Model 5:Interval, robust S.E.**	
WTP transform	none		square root		$\log_e$		none		$\log_e$	
Model fit	$R^2 = 0.1500$		$R^2 = 0.2031$		$R^2 = 0.2182$		Pseudo R^2 = 0.0185		Max. Likelihood $R^2 = 0.212$	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	z
INCOME	3.09 (1.42)	2.17*	0.30 (0.11)	2.72**	0.13 (0.05)	2.71**	3.49 (1.46)	2.40*	0.15 (0.05)	2.67**
MUDAHP	45.38 (11.44)	3.97**	4.66 (0.98)	4.75**	2.04 (0.44)	4.59**	55.40 (13.26)	4.18**	2.38 (0.54)	4.41**
LOCAL	3.75 (4.17)	0.90	-0.18 (0.49)	-0.36	-0.29 (0.23)	-1.24	2.94 (6.89)	0.43	-0.33 (0.26)	-1.31
MODE	4.02 (8.09)	0.50	0.56 (0.76)	0.73	0.35 (0.34)	1.02	5.48 (10.09)	0.54	0.46 (0.35)	1.30
EXPERT	-7.89 (6.91)	-1.14	-0.02 (0.69)	-0.03	0.14 (0.30)	0.47	-6.17 (8.79)	-0.70	0.24 (0.27)	0.87
CLIMATE_ FUTURE	17.68 (4.52)	3.91**	1.58 (0.37)	4.29**	0.71 (0.17)	4.22**	18.92 (4.99)	3.79**	0.76 (0.20)	3.85**
KNOWTIDAL	6.36 (5.75)	1.10	0.07 (0.42)	0.15	-0.09 (0.19)	-0.44	6.12 (5.69)	1.08	-0.12 (0.21)	-0.56
OWNELECT	-5.24 (10.63)	-0.49	-0.58 (0.78)	-0.74	-0.30 (0.34)	-0.87	-8.38 (10.39)	-0.81	-0.37 (0.46)	-0.81
GENDER	-10.07 (4.43)	-2.27*	-0.94 (0.37)	-2.56*	-0.42 (0.17)	-2.52*	-11.38 (4.98)	-2.28*	-0.47 (0.18)	-2.55*
AGE	0.73 (1.62)	0.45	0.12 (0.14)	0.89	0.09 (0.06)	1.49	1.04 (1.86)	0.56	0.11 (0.07)	1.56
SIZEHHOLD	-4.44 (4.58)	-0.97	-0.50 (0.41)	-1.24	-0.24 (0.18)	-1.31	-6.85 (5.46)	-1.25	-0.30 (0.19)	-1.54
NATUREGRP	-4.54 (5.00)	-0.91	-0.11 (0.46)	-0.24	0.03 (0.21)	0.15	-3.92 (6.12)	-0.64	0.07 (0.21)	0.31
SPORT	-4.29 (5.50)	-0.78	-0.55 (0.43)	-1.28	-0.24 (0.19)	-1.24	-5.38 (5.79)	-0.93	-0.27 (0.22)	-1.20
ANGLING	0.62 (6.87)	0.09	-0.13 (0.56)	-0.23	-0.17 (0.26)	-0.65	-2.45 (7.74)	-0.32	-0.26 (0.35)	-0.74
_cons	-6.28 (13.87)	-0.45	0.82 (1.07)	0.77	0.89 (0.48)	1.85	-14.86 (14.27)	-1.04	0.55 (0.50)	1.10

Standard errors of the coefficients are given in brackets. Significance of t- or z-statistic: ** < 1%, * < 5%

Refusal to disclose income level

The models show that income is a significant explanatory variable for WTP, but including the income variable reduced the sample size, because 20% of respondents refused to disclose their income. Previous versions of the model suggest that excluding income from the model reduces the fit (Table 24) despite the increased sample size. What was not considered in these earlier models was whether those who refused to disclose their income had different preferences to those prepared to provide this information. The model was therefore re-run excluding the income variable but including a dummy to account for non-disclosure of income information. This variable was not significant in the model (z = -1.58, p = 0.114) but AHP weight, strong agreement that climate change will be a problem in the future and gender remained significant.

Protest responses

18% of respondents did not express a positive willingness to pay (WTP) to reduce intertidal habitat loss by 70ha. This included respondents who failed to provide a valid answer to the valuation question, stating that they did not know how much they would be willing to pay, as well as genuine zero bids (Table 26). Other respondents whose stated WTP was zero were judged to be protesting, as they agreed or strongly agreed with at least one of the statements designed to identify protest responses. The most common protest, expressed by about 70% of zero bidders in North Devon and Wellington, was an objection to incurring higher electricity bills to pay for a tidal barrage. Fewer respondents objected to having a barrage in the Taw Torridge *per se*, or to paying for any form of renewable energy. Within the limitations of the data, this suggests that objections to a barrage may be more strongly driven by economic (as opposed to ecological or social) factors, but that other forms of renewable energy may be preferred to tidal barrages.

Table 26. The percentage of respondents from each of the sample groups giving particular responses when asked for their willingness to pay to reduce intertidal habitat loss by 70ha.

	Full sample	North Devon	Wellington	Experts	Other academics
n	419	221	80	56	62
Positive WTP	81.9	78.3	77.5	92.9	90.3
Don't know/Missing data	2.6	2.7	5.0	0.0	1.6
Protest response	11.5	14.0	15.0	3.6	4.8
Genuine zero bid	4.1	5.0	2.5	3.6	3.2

The econometric analysis was repeated, this time excluding those respondents who had been identified as protesters. The resulting WTP to reduce the loss of intertidal habitat by 70ha was significantly higher than when these responses had been included (Mann Whitney, $z = -2.630$, $p = 0.009$) (Table 27). The WTP of the sample excluding protest responses was modelled using interval regression with the full list of explanatory variables (as per Table 22), and income, gender, the AHP weighting for mudflat loss, and strong agreement that climate change would be a problem in the future were once again a significant influence on WTP (Table 28). Two additional variables were also significant when protesters were excluded: WTP was lower for respondents who lived near the Taw Torridge estuary, and for those completing the online survey.

Table 27. Summary statistics for the WTP to reduce mudflat loss by 70ha, comparing samples excluding and including protest responses

	Including protests	**Excluding protests**
n	408	360
Arithmetic Mean WTP (£)	26.17	29.58
standard error	1.87	2.04
95% confidence interval	22.5; 29.8	25.5; 33.6
Median WTP (£)	11	13
Minimum (£)	0	0
Maximum (£)	250	250

Table 28. The regression coefficients (coef.) and associated z-statistic for versions of the interval regression model, using datasets including and excluding protest responses, using variables described in Table 22.

	Including protests		**Excluding protests**	
n	310		284	
Maximum Likelihood R^2	0.212		0.237	
	Coef.	z	Coef.	z
INCOME	0.15 (0.05)	2.67**	0.11 (0.05)	2.15*
MUDAHP	2.38 (0.54)	4.41**	2.16 (0.44)	4.93**
LOCAL	-0.33 (0.26)	-1.31	-0.46 (0.20)	-2.26*
MODE	0.46 (0.35)	1.30	0.63 (0.29)	2.17*
EXPERT	0.24 (0.27)	0.87	0.06 (0.24)	0.26
CLIMATE_FUTURE	0.76 (0.20)	3.85**	0.91 (0.17)	5.39**
KNOWTIDAL	-0.12 (0.21)	-0.56	-0.13 (0.19)	-0.71
OWNELECT	-0.37 (0.46)	-0.81	-0.27 (0.40)	-0.67
GENDER	-0.47 (0.18)	-2.55*	-0.45 (0.16)	-2.79**
AGE	0.11 (0.07)	1.56	0.10 (0.06)	1.64
SIZEHHOLD	-0.30 (0.19)	-1.54	-0.23 (0.17)	-1.31
NATUREGRP	0.07 (0.21)	0.31	0.07 (0.19)	0.39
SPORT	-0.27 (0.22)	-1.20	-0.25 (0.20)	-1.26
ANGLING	-0.26 (0.35)	-0.74	0.21 (0.30)	0.68
_cons	0.55 (0.50)	1.10	0.86 (0.44)	1.96

Standard errors of the coefficients are given in brackets.
Significance of z-statistic: ** < 1%, * < 5%

Scope sensitivity

Respondents who expressed a positive WTP to reduce mudflat loss by 70ha were also presented with a second valuation scenario, in order to test the scope sensitivity of the WTP values. In this second scenario, respondents were asked for their WTP to reduce mudflat loss by 140ha. All respondents were told about this alternative barrage before any valuation questions were asked, and when asked about the second scenario, they were also reminded of the WTP they had expressed to reduce habitat loss by 70ha. For the responses to show sensitivity to scope, the WTP in the second scenario should be higher that of the first scenario.

For the full sample, and for each of the four subsamples individually, the average WTP to reduce mudflat loss by 140ha was significantly higher than the WTP to reduce mudflat loss by 70ha (Table 29) (Wilcoxon signed-ranks tests, $p<0.001$ for all). The values calculated overestimate actual WTP for 140ha because only respondents with a positive WTP were included, although they remain valid for comparative purposes. There was no significant difference in the average WTP to reduce habitat loss by 70ha or 140ha between individuals whose bid increased in the second scenario and those who did not show scope sensitivity (Mann-Whitney, 70ha: $z = 1.645$, $p = 0.0999$; 140ha: $z = 0.928$, $p = 0.3534$) (Table 30).

Table 29. Summary statistics to compare WTP to reduce mudflat loss by 70ha and by 140ha, for each of the four sample groups

	Full sample		North Devon		Wellington		Experts		Other academics	
n	338		169		58		52		56	
Reduction in mudflat loss	70ha	140ha	70ha	140ha	70ha	140ha	70ha	140ha	70ha	140ha
Mean WTP (£)	31.47	35.95	30.65	31.43	26.93	30.44	30.43	40.12	39.84	48.70
Standard Error	2.14	2.31	3.41	3.38	4.39	4.55	3.95	4.90	5.20	6.89
Median WTP (£)	13.00	22.50	11.00	13.00	13.00	22.50	22.50	32.50	24.50	32.50
Min. WTP (£)	0.25	0.17	0.25	0.17	0.62	0.17	1.25	1.25	0.62	0.62
Max. WTP (£)	250	250	250	250	200	200	137.5	137.5	162.5	187.5

Table 30. Summary statistics for the WTP to reduce mudflat loss by 70ha and 140ha, comparing respondents who showed scope sensitivity and those whose WTP did not change

	No scope sensitivity	**Scope sensitivity**	
n	199	139	
Reduction in mudflat loss	70ha/140ha	70ha	140ha
Mean WTP (£)	35.73	25.37	36.27
standard error	3.13	2.59	3.41
95% confidence interval	29.56; 41.91	20.26; 30.49	29.53; 43.01
Median WTP (£)	13	13	22.5

At the level of individual respondents, scope sensitivity was low, particularly in the face-to-face surveys with the general public (Table 31). A logit model was used to determine which variables predicted the presence of scope sensitivity. This model used the same variables as before (Table 22), with the addition of a variable representing WTP to reduce habitat loss by 70ha (*WTP(70ha)*). This stated WTP in the first scenario and the AHP rating for mudflat loss were significant predictors of scope sensitivity at the 1% level (Table 32). The relationship between AHP weight for mudflat loss and scope sensitivity was explored further, and showed a convincing linear trend ($R^2 = 0.40$). The responses of 36% of those with an AHP weight of less than 0.4 showed sensitivity to scope, increasing to 55% of those with an AHP weight of 0.6 or more (Figure 31).

Table 31. The percentage of respondents in each sample group with different ratios of WTP to reduce habitat loss by 140ha compared to WTP to reduce habitat loss by 70ha.

	n	WTP ratio (140ha:70ha) <1	1	1 – 2	2	>2
Full sample	338	3.0	58.9	22.5	10.9	4.7
North Devon	169	3.0	65.1	16.6	10.1	5.3
Wellington	61	4.9	62.3	18.0	11.5	3.3
Experts	52	0.0	42.3	38.5	17.3	1.9
Other academics	56	3.6	51.8	30.4	7.1	7.1

Table 32. Output of a logit model to determine explanatory variables for the presence of scope sensitivity. Descriptions of the variables are provided in Table 22.

n	267		
LR $\chi^2(4)$	40.67	Log likelihood	-160
p	0.0004	Pseudo R^2	0.1129

	Coef.		t	95% Conf. Interval	
WTP (70ha)	-0.014	(0.005)	-3.00**	-0.024	-0.005
INCOME	-0.137	(0.087)	-1.58	-0.307	0.033
MUDAHP	2.440	(0.826)	2.95**	0.821	4.059
LOCAL	-0.012	(0.401)	-0.03	-0.799	0.774
MODE	-0.862	(0.578)	-1.49	-1.995	0.271
EXPERT	0.067	(0.481)	0.14	-0.875	1.009
CLIMATE_FUTURE	0.158	(0.309)	0.51	-0.448	0.764
KNOW_TIDAL	0.055	(0.328)	0.17	-0.588	0.697
OWNELECT	-0.746	(0.715)	-1.04	-2.148	0.655
GENDER	0.041	(0.287)	0.14	-0.522	0.603
AGE	0.003	(0.104)	0.03	-0.201	0.208
SIZEHHOLD	-0.607	(0.312)	-1.95	-1.218	0.004
NATUREGRP	-0.101	(0.345)	-0.29	-0.777	0.574
SPORT	-0.270	(0.350)	-0.77	-0.956	0.417
ANGLING	-0.286	(0.503)	-0.57	-1.272	0.700
_CONS	0.419	(0.814)	0.51	-1.177	2.015

Standard errors of the coefficients are given in brackets.
Significance of t-statistic: ** < 1%, * < 5%

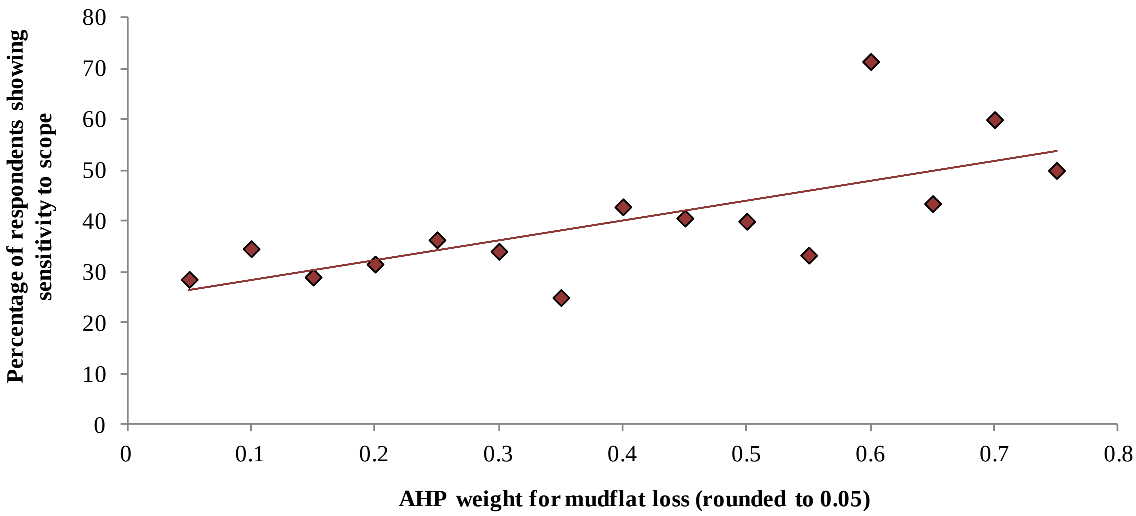

Figure 31. The relationship between the likelihood of responses showing sensitivity to scope and the Analytic Hierarchy Process weighting for mudflat loss given by the respondent (R^2 = 0.40).

7.3 Phase two: Choice experiment

Survey administration

123 face-to-face interviews were completed. Again, not all respondents completed all questions. In particular, 25% of respondents refused to disclose their income, a similar proportion to those who refused the same question in the contingent valuation. The surveys took on average 15 minutes to complete (range 10 to 25 minutes). Respondents appeared to find the survey a straightforward exercise: 83% of respondents were judged by the interviewer to have found the survey "very easy" to complete, and 96% were "not at all annoyed by it".

Description of sample population

The socio-economic characteristics of the sample were very similar to those of the North Devon respondents who completed the contingent valuation survey (Table 33). The observed differences in education levels, income, employment and proportion of respondents who generate their own electricity were not statistically significant.

Table 33. Key statistics describing the sample population participating in the choice experiment, including a comparison with the North Devon sample from the contingent valuation. χ^2 were not significant (p>0.05).

	Choice experiment	Contingent valuation	χ^2
Number of respondents	123	221	
% of male respondents	55.3	50.2	0.81
Median age group category (yrs)	35 – 44	35 – 44	1.98
% of respondents who are:			8.36
Employed	52.0	50.7	
Retired	26.0	28.3	
Students	0.8	6.4	
Otherwise not working	21.1	14.6	
Median annual household income category (£000s)	15 – 25	25 – 35	5.16
Median monthly electricity bill category (£)	31 – 40	31 – 40	9.45
% of respondents with degree	18.0	29.4	2.76
Mean number in household	3.0	2.8	
% of respondents who are members of a conservation group	13.9	13.6	
% of respondents who generate at least some of their own electricity	3.3	8.2	3.19

Attitudes to energy issues were also closely matched between the two North Devon groups, with only a minority of respondents disagreeing with the statements that "climate change is a real problem now", "climate change will be a real problem in the future", "burning fossil fuels (coal, oil and gas) is a major cause of climate change" and "the UK should rely less on imported fuel and produce more energy from sources within its own borders, even if this means electricity bills go up" (Figure 32). Knowledge about tidal barrages was again low, with 75% of the respondents reporting that they were "not at all informed" or "not very well informed" about barrages (Figure 33). Only relatively small numbers of respondents preferred wind or nuclear energy to tidal barrages: 50% of the sample disagreed or strongly disagreed with the statement “Building more wind farms would be better than building tidal barrages, even if this costs me more money” rising to 75% disagreeing or strongly disagreeing with a similar statement about nuclear energy (Figure 34). Statistically significant differences were apparent in the levels of participation in recreational activities: respondents to the choice experiment participated in birdwatching or walking/cycling on coastal paths less frequently than those who took part in the contingent valuation (Table 34).

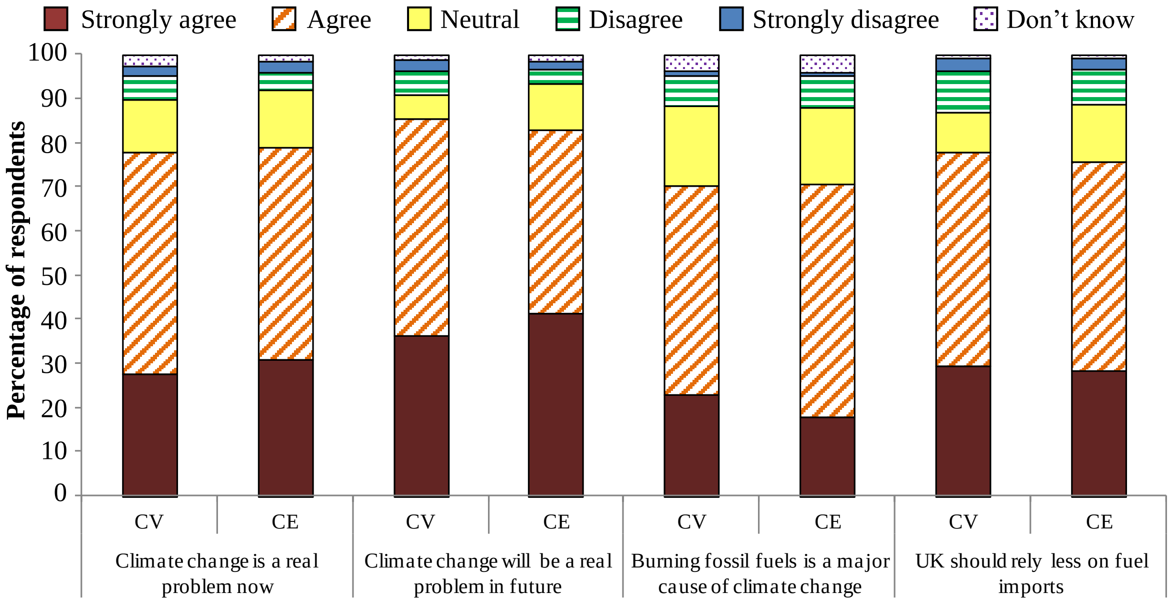

Figure 32. A comparison of the levels of agreement with statements about climate change and energy security between respondents from North Devon who participated in the contingent valuation (CV) and choice experiment (CE)

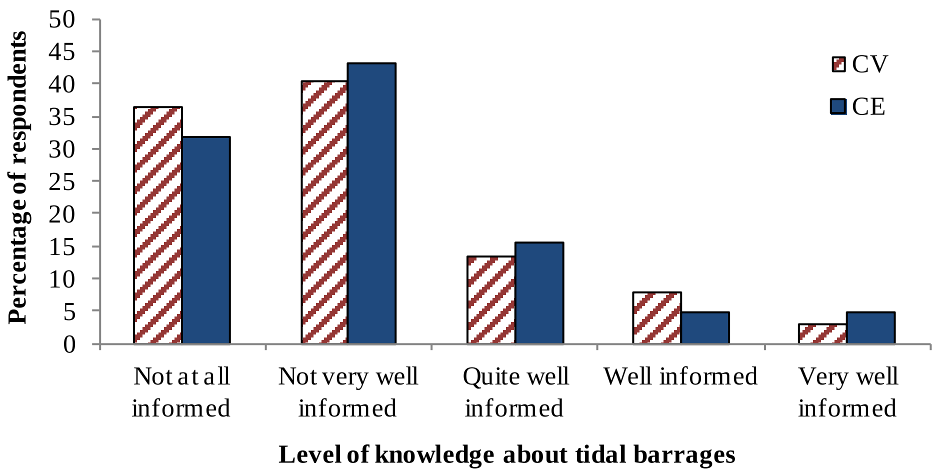

Figure 33. Level of knowledge about tidal barrages amongst respondents from North Devon who participated in the contingent valuation (CV) and choice experiment (CE)

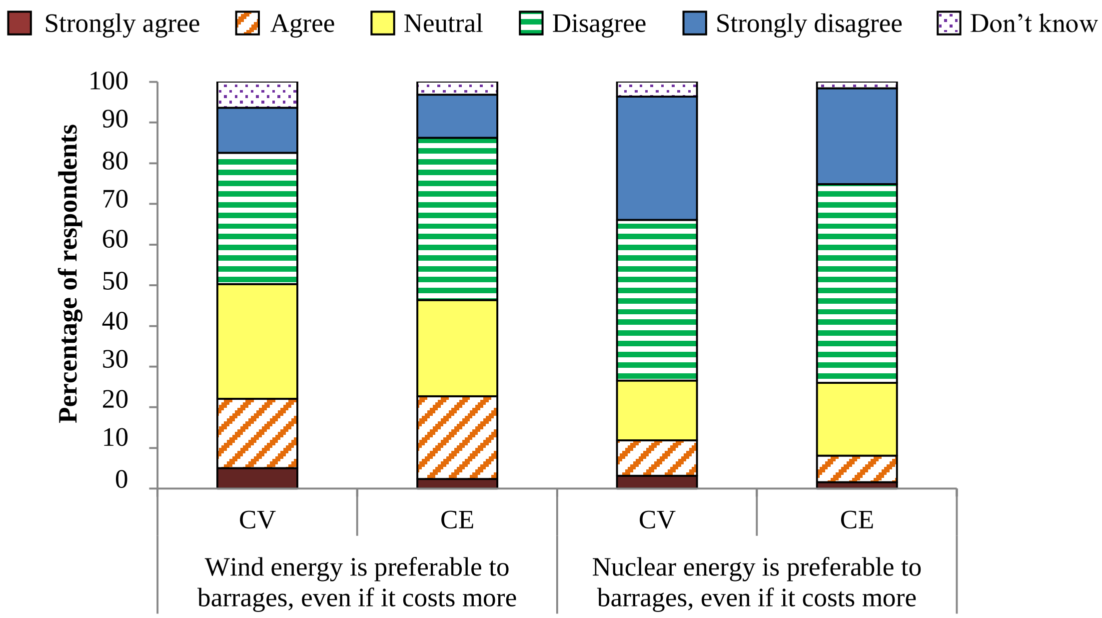

Figure 34. A comparison of the levels of agreement with statements that wind energy or nuclear power would be preferable to tidal barrages between respondents from North Devon who participated in the contingent valuation (CV) and choice experiment (CE)

Table 34. The percentage of respondents who take part in particular recreational activities at least once per year, including a comparison with the North Devon sample from the contingent valuation.

	Choice experiment	Contingent valuation	χ^2
Number of respondents	123	221	
Watersports	36.6	37.3	1.16
Walking/cycling on coastal/river paths	82.1	87.8	16.54**
Birdwatching	30.9	53.6	29.86**
Recreational angling/crabbing	18.7	25.0	2.01

Significance of χ^2 statistic: ** < 1%, * < 5%

Protest responses

25 respondents (20% of the sample) did not choose either barrage option for any of the eight choice cards. Two respondents refused to choose as they felt they lacked information, and the remainder chose the 'neither' option. Follow-up questions identified one respondent as a genuine zero bidder, and the remaining 22 respondents (18%) as protesters. There were significant differences in the responses to these follow-up questions between zero bidders and those who selected barrage options (Pearson's χ^2, p<0.007) (Figure 35). This gives some credibility to the use of these questions as tool to identify protesters, although the sample sizes were small (n=22). The proportion of protest responses was the same as that for the North Devon respondents to the contingent valuation survey (Pearson's χ^2 = 0.427, p= 0.513). No respondent chose the same barrage option on each choice card, suggesting that those choosing a barrage option were giving due consideration to their responses rather than reducing their cognitive burden by choosing the same option every time.

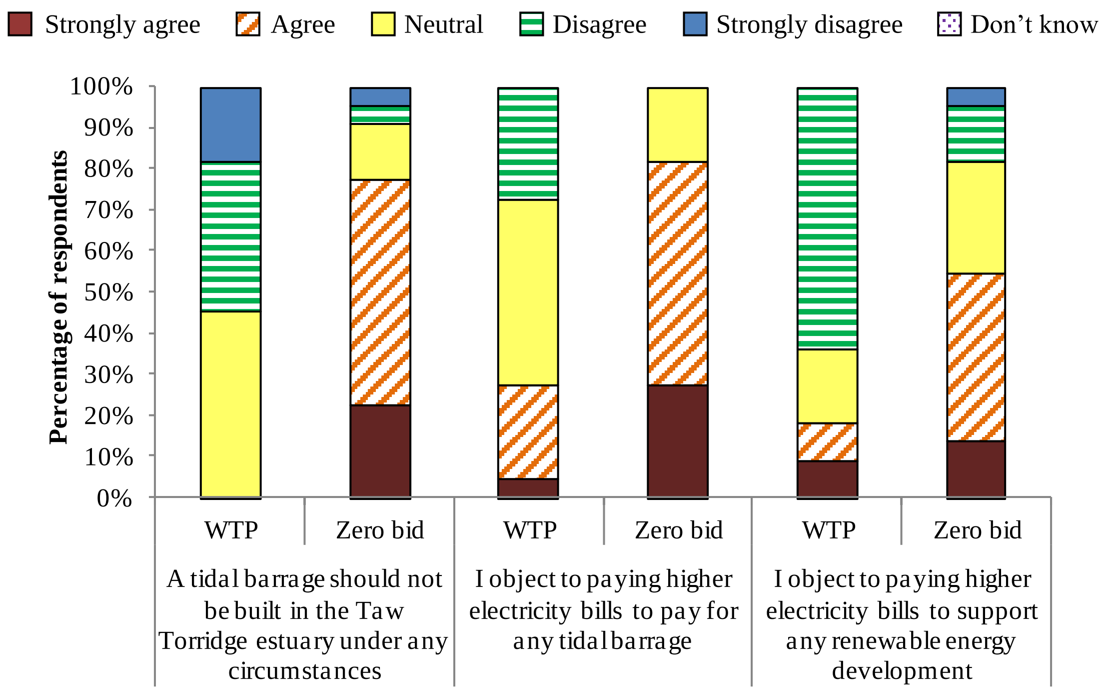

Figure 35. The level of agreement with statements designed to identify protesters amongst those always choosing the status quo option (zero bid) and those who chose barrage options (WTP)

Econometric modelling

Protesters were excluded from the data set in line with common practice, and a conditional logit model was used to assess the influence of the different barrage attributes on respondent choice (Table 35). All of the barrage attributes were significant factors in the model, and showed the expected sign: respondents preferred barrages which provided more power and protected more homes from flooding, but not those which increased cost or loss of habitat (Table 36). However, the conditional model failed to show independence of irrelevant alternatives (Hausman test: χ^2 = 5.74; p = 0.2198), and so the data was re-examined using a mixed logit model, which again showed that all attributes were significant, with the expected sign (Table 36). The likelihood ratio also showed that the mixed logit model was preferred (LR χ^2 = 179.05; p < 0.0001).

Table 35. The barrage attributes used in the choice experiment

Attribute	Description	Levels	Predicted sign
COST	Additional annual charge on electricity bill (£)	0, 3, 12, 48, 196	–
POWER	Number of homes powered	0, 14500, 21000	+
FLOOD_PROTECT	Number of homes given additional flood protection	0, 1900, 2400	+
HABITAT_LOSS	Quantity of mudflat lost (ha)	0, 70, 140	–

Table 36. Output of the conditional (CL) and mixed logit (MXL) models. Descriptions of the variables used are provided in Table 35.

	CL	MXL
N	99	99
Log likelihood	-644	-544

	CL	MXL
χ^2	319	179
p	0.0000	0.0000

	Conditional logit			Mixed logit		
	Coef.		z	Coef.		z
COST	-0.012	(0.001)	-11.16**	-0.015	(0.001)	-12.00**
POWER	1.279	(0.185)	6.90**	1.835	(0.253)	7.23**
FLOOD_PROTECT	1.180	(0.207)	5.70**	2.171	(0.304)	7.15**
HABITAT_LOSS	-0.904	(0.100)	-9.07**	-1.270	(0.174)	-7.29**

Standard errors of the coefficients are given in brackets. Significance of z-statistic: ** < 1%

Socio-economic factors also have the potential to influence choice, and so the model was extended to examine the interaction of individual-specific variables (Table 37) with barrage attributes. Due to the large number of possible interaction terms (48), this model was constructed using forward selection (in which additional variables were tested in the model one at a time, and the combination with the lowest final loglikelihood added at each step until the difference in the loglikelihood ratio was not significant). The best fitting model (Table 38) included four interaction terms: cost with age and size of household, and habitat loss with frequency of participation in both watersports and walking/cycling on coastal/river paths. However, only the latter two had a significant influence on choice. The implicit prices for the barrage attributes were also calculated (Table 39).

Table 37. The socio-economic variables used to construct interaction terms for the mixed logit model

Variable	Type	Description
INCOME	Interval	Income (categories are pooled below £15,000 and above £55,000 due to low respondent numbers in those categories)
CLIMATE_ FUTURE	Dummy	1= strongly agrees (likert 5/5) that climate change will be a problem in the future
KNOW_ TIDAL	Dummy	1 = at least quite well informed about tidal barrages
OWNELECT	Dummy	1= generates at least some household electricity with e.g. solar panels
GENDER	Dummy	0= female; 1= male
AGE	Interval	Age group
SIZEHHOLD	Dummy	1 = household size exceeds 2
NATUREGRP	Dummy	1= member of nature/conservation group
SPORT	Dummy	1= takes part in watersports at least once a month
WALK	Dummy	1= walks/cycles on coastal/river paths at least once a month
BIRD	Dummy	1= goes birdwatching at least once a month
ANGLING	Dummy	1= goes angling or crabbing at least once a month

Table 38. The output of the best fitting mixed logit model including interactions between barrage attributes and the socio-economic characteristics of the respondent, using variables described in Table 37.

n	71	χ^2	189
Log likelihood	-330	p	0.0000

	Coef.		z	95% Conf. Interval	
COST	-0.050	(0.014)	-3.63**	-0.078	-0.023
POWER	2.643	(0.418)	6.33**	1.824	3.462
FLOOD_PROTECT	3.900	(0.564)	6.92**	2.795	5.005
HABITAT_LOSS	-0.888	(0.298)	-2.99**	-1.471	-0.305
*COST*AGE*	0.003	(0.002)	1.23	-0.002	0.008
*COST*SIZEHHOLD*	-0.009	(0.007)	-1.31	-0.022	0.004
*HABITAT_LOSS*SPORT*	-1.422	(0.678)	-2.10*	-2.752	-0.092
*HABITAT_LOSS*WALK*	-1.166	(0.419)	-2.78**	-1.987	-0.345

Standard errors of the coefficients are given in brackets.
Significance of z-statistic: ** < 1%, * < 5%

Table 39. The implicit prices of the barrage attributes

Attribute	**Implicit price (£)**	**S.E.**
Power (per 6,500 homes)	52.86	16.56
Flood protection (per 500 homes)	78.00	23.93
Reduction in habitat loss (per 70 hectares)	17.76	7.60

Comparison with responses to the Contingent Valuation

The results of the choice experiment were compared with the North Devon sample from the contingent valuation. The Analytic Hierarchy Process weights were not included in the model, so that the same list of explanatory variables was used for both the contingent valuation and choice experiment. Two socio-economic variables were significant in the model (Table 40): older people and those who strongly believed that climate change would be a problem in the future were willing to pay more to reduce habitat loss. The mean willingness to pay calculated from the contingent valuation was £28.17 (S.E £3.19), a comparable result to the implicit price for reducing habitat loss derived from the choice experiment (£17.76, S.E. £7.60).

Table 40. Output of an interval regression model for the contingent valuation survey undertaken by North Devon respondents , using variables described in Table 37.

n	143	χ^2	42.8
Log likelihood	-485	p	0.0000

	Coef.		z	95% Conf. Interval	
INCOME	0.136	(0.086)	1.57	-0.034	0.305
CLIMATE_FUTURE	0.733	(0.266)	2.76**	0.213	1.254
KNOW_TIDAL	-0.474	(0.358)	-1.32	-1.177	0.228
OWNELECT	-0.917	(0.579)	-1.59	-2.051	0.217
GENDER	-0.546	(0.291)	-1.88	-1.115	0.024
AGE	0.202	(0.086)	2.36*	0.034	0.370
SIZEHHOLD	0.015	(0.345)	0.04	-0.661	0.690
NATUREGRP	0.367	(0.348)	1.05	-0.315	1.048
SPORT	-0.068	(0.362)	-0.19	-0.778	0.642
WALK	0.157	(0.520)	0.30	-0.862	1.175
BIRD	0.339	(0.333)	1.02	-0.313	0.991
ANGLING	0.296	(0.279)	1.06	-0.251	0.843
_CONS	0.928	(0.499)	1.86	-0.050	1.906

Standard errors of the coefficients are given in brackets.
Significance of z-statistic: ** < 1%, * < 5%

7.4 Summary

The survey results showed that there was general agreement amongst respondents that climate change was real and a manmade problem and also that most were not well informed about tidal barrages. The Analytic Hierarchy Process demonstrated that both environmental and social attributes of barrage were important, and also that the importance to respondents of mudflat loss is related to the time they spend enjoying the coast and nature.

Most respondents expressed a positive willingness to pay to reduce mudflat loss, although evidence of protest bidding was found. Household income, the respondent's AHP weight for mudflat loss, his/her attitude to climate change and gender were significant variables in the contingent valuation models. When protesters were excluded, the survey mode and distance from affected site also became significant variables in the econometric models. Scope sensitivity was low, and the level of concern for mudflat loss (as expressed through the AHP weight) appeared particularly significant in predicting likelihood that respondents would show scope sensitivity.

In the choice experiment, the four barrage attributes were all significant factors in the model, and showed the expected sign. When interaction terms were also included in the model, only the interactions of habitat loss with participation in watersports and walking/cycling on coast/river paths were significant. Very similar values for mudflat loss were derived from both the choice experiment and contingent valuation techniques. The results of the valuation studies are discussed in the following chapter.

8 Discussion

8.1 Introduction

The results of the empirical research showed that the proposed scenarios were suitable for eliciting monetary values for avoiding estuarine mudflat loss and, through the choice experiment, for two additional barrage attributes: renewable energy produced and flood protection provided. The contingent scenario did, however, elicit protest responses, and the motivation for these is discussed.

The validity and reliability of the value elicited are examined by considering scope sensitivity, distance decay and the influence of respondents' income, pro-environmental attitude, and use and understanding of mudflat ecosystems. The consistency of WTP across the two elicitation techniques is also assessed. The choice experiment and the Analytic Hierarchy Process (AHP) also provided an insight into the relative importance to respondents of environmental and social attributes of tidal barrages. In discussing the AHP results more generally, the use, and relevance, of the consistency ratio is also evaluated.

The chapter concludes by considering the policy implications of the results: the transferability of the value obtained is discussed, and its possible use in cost benefit analysis explored.

8.2 Eliciting a monetary value for UK estuarine intertidal mudflats

Both the contingent valuation and choice experiment elicited a positive willingness to pay from at least 80% of respondents, indicating that the vast majority of members of the public within the study areas value intertidal mudflat to the extent that they would be willing to incur higher energy bills in order to reduce mudflat loss. Only 4% of respondents to the contingent valuation (and 2% to the choice experiment) were judged to have no value for mudflats.

Protest responses

How the respondent engages with the scenario may influence his stated WTP. A respondent may not state his true WTP if he rejects an aspect of the contingent scenario but may instead state a WTP of zero, as a means of protest (Meyerhoff and Liebe, 2008). The survey instrument included specific questions that attempted to determine whether intertidal mudflats really did have no value to respondents making zero bids. Additional anecdotal evidence was obtained, which suggested that protest and strategic behaviour did indeed occur amongst the respondents.

One interviewer spent time soliciting some broader comments from interviewees in North Devon, which highlighted particular areas that may have affected responses. Interviewees were clearly told that the survey was simply a research exercise and did not relate to any actual plans being considered, but responses suggest that a proportion of respondents ignored or did not believe this statement, and drew their own conclusions about the purpose of the survey or the underlying research question. There appeared to be a fairly widespread tendency for respondents to believe that the research was a precursor to an actual barrage proposal or that its purpose was to solicit support for (or opposition to) barrages in general. If respondents focused on any assumption they may have had rather than answering the questions as actually asked, then their responses may become more strategic.

A specific example of strategic use of a zero bid was a respondent who refused to pay because she opposed any barrage, and she opposed barrages because she would not sanction any impact on the mudflat. In this situation, the environment was valued by the respondent, but this value was not reflected in her stated WTP. Other respondents may have protested against paying extra on their electricity bill, but not against paying to protect mudflats. From 14 October (shortly before the close of online survey), there was widespread coverage in the media of an Ofgem report which stated that energy companies' annual profits had increased from £15 to £125 per dual-fuel customer (see e.g. The Guardian, 2011). This, and similar, news may have influenced at least one respondent, who emailed the author expressing objections to the levels of profits made by energy companies. In both of these cases, a different scenario could have elicited from the respondent a positive WTP to conserve estuarine intertidal mudflats, but as WTP is context specific an alternative scenario may have no relevance to tidal barrage development.

Protest and strategic responses can bias the central tendency of WTP data (Boyle, 2003). They are routinely excluded from contingent valuation, but this attracts controversy because such exclusions tend to be *ad hoc*, owing to the lack of a universal, conceptually robust rationale (Jorgensen et al., 1999; Meyerhoff and Liebe, 2008). The development of procedural rules is difficult, because the identification, treatment and influence of protest responses is often poorly reported, and where the issue is examined in detail, no clear patterns in the factors influencing protest responses have yet emerged (Meyerhoff and Liebe, 2010).

Within this study, the questions to identify protesters were asked to both those stating a zero WTP and to a corresponding number of respondents with a positive WTP. The process provoked very different responses from the two groups, suggesting that the questions were a reasonable means of identifying those whose zero bid resulted from a rejection of some aspect of the scenario, and so could provide some justification for their exclusion from the model.

The exclusion of protest responses from the contingent valuation did inflate the mean and median WTP values by approximately 15%. However, the same four core explanatory variables (income, gender and two measures of pro-environmental attitude) affected WTP regardless of whether protesters were excluded or not, suggesting that the key conclusions about the influences on WTP remain valid. Two additional variables did become significant, however, when protesters were excluded from the model. The first of these was survey mode, with those completing the face-to-face survey having a higher WTP. This suggests a social desirability bias, with respondents reacting to the presence of the interviewer (Champ and Welsh, 2007). The distance between a respondent's home and the Taw Torridge also became significant when protesters were excluded, and the issue of distance decay will be discussed in more detail below.

8.3 Validity of the elicited willingness to pay with regard to economic theory

Scope Sensitivity

The quantity of the environmental good is expected to influence WTP: the issue of scope sensitivity and its implications for the validity of contingent valuation has long been debated. Where WTP fails to show an increase with increasing provision of the environmental good, some researchers hypothesise that the stated WTP may represent the purchase of the "warm glow" that results from a charitable act, rather than the economic value of the good (Kahneman and Knetsch, 1992). Researchers have also cited the similarity between WTP values across a diverse range of environmental goods as evidence that the stated value is a respondent's WTP for any good cause and is not specific to the good in question (Harrison, 1992). Proponents of contingent valuation have criticised the methodology of those finding scope insensitivity (Smith 1992; Carson and Mitchell, 1993), but have also looked more closely at respondents' motivations to suggest situations in which a lack of scope sensitivity may be entirely consistent with individual preferences (Heberlein et al., 2005; Amiran and Hagen, 2010).

This study passed the scope test in that the average WTP to reduce mudflat loss by 140ha was significantly higher than that to reduce loss by 70ha. Scope sensitivity was apparent at the aggregate level, but was not shown by the majority of individuals; 62% of respondents stated the same WTP regardless of the affected area of habitat. This could potentially be because the difference in habitat loss between the two scenarios is relatively small (70ha). Respondents failing to show scope sensitivity may simply not perceive there to be any real difference between the scenarios (Arrow et al., 1993).

Respondents were told in advance that there would be two valuation scenarios. However, when factors that might influence scope sensitivity were modelled, a significant, and negative, relationship was found between a respondent's WTP in the first scenario and the likelihood of her response to the second scenario showing sensitivity to scope. This suggests that some respondents may have used the first scenario to state their maximum WTP, regardless of the change in status of the environmental good. This was perhaps because they viewed their contribution as a charitable donation or had a self-imposed budget ceiling (Chilton and Hutchinson, 2003) and exhausted this budget in the first round.

The level of concern expressed by the respondent for the environmental good (defined by the AHP weight for mudflat loss) also appeared to influence the likelihood of his response showing scope sensitivity. This suggests that those with strong concern for the good in question are more likely to be stating a value that specifically relates to that environmental good. Where respondents are less concerned, the lack of scope sensitivity may indicate that their WTP reflects a contribution to environmental protection in general, rather than an economic value for the good in question.

Some outlying results (3% of the sample) displayed a decreased WTP when the level of habitat loss was reduced. The expectation is that, *ceteris paribus*, respondents who are able to pay should be willing to pay more to secure a larger quantity of the good (Powe and Bateman, 2004). It is difficult to propose a hypothesis for this observation: when a respondent had already expressed a positive WTP for some reduction in habitat loss, his utility would decrease if the habitat loss were further reduced. It is possible that in these cases the respondents thought that they were being asked to make a further payment in addition to that already stated, or that they otherwise misunderstood the valuation scenario.

At the other end of the scale, six respondents were willing to pay at least five times more to reduce habitat loss by a factor of two. However, their initial WTP was usually very low, and so perhaps their response to the first scenario was actually a form of protest: they did not really feel that reducing habitat loss by 70ha was sufficient and their utility was not truly increased until mudflat loss was further reduced. Alternatively, the respondents may not believe that a barrage resulting in a large loss of habitat would be permitted, and so may not have engaged with the scenario. A respondent's belief in the likelihood of one or other scenario being implemented has been suggested as a factor in apparent scope insensitivity (Powe and Bateman, 2004).

Distance Decay

The study included sites beyond the immediate area of Taw Torridge in order to assess whether distance from the affected area affected WTP. Some distance decay was anticipated: it is reasonable to hypothesise that those living further from a site would value it less, as their familiarity with the ecosystem and opportunities to use it are reduced. This effect has indeed been shown with previous studies of wetland areas (Bateman and Langford, 1997; Pate and Loomis, 1997). However, no distance decay effect was observed in this study. This is potentially because the distant sites were not sufficiently separated from the study site: all respondents lived within

50km of the Taw Torridge and the majority of non-resident respondents had at least some familiarity with the Taw Torridge (68% had visited it at least once in the last five years).

Residence in the area local to the Taw Torridge did become significant when protesters were excluded, but with a negative sign. This is not an entirely unique finding, however, as such an 'inverse distance decay' effect, with those in closest proximity having lower WTP, has been observed in other research (Boxall et al., 2012). This finding is potentially a statistical anomaly resulting from the reduced sample size. Alternatively, the result could suggest a real effect. Data was not collected on the purpose of visits to the Taw Torridge, but it is reasonable to assume that they were primarily recreational, given the popularity of the area with tourists. If this is the case, it is possible that non-residents value the Taw Torridge area more highly than local people, as they view it as somewhere associated particularly with leisure and enjoyment, whereas to residents it is their everyday environment.

8.4 The influence of personal characteristics on willingness to pay

Elucidating the motivation for stated values, and how this conforms to economic theory and expectations, is important in establishing the validity of the result obtained. Understanding the variation in values across the population is also fundamental in cost-benefit analysis. In this study, the econometric model for the contingent valuation identified four core variables that were significant in predicting WTP, out of 14 explanatory variables utilised in the models.

Income and gender

Income was a significant explanatory variable, consistent with economic theory, as those who are better off have a lower marginal utility of income and hence a greater WTP is expected. The general tendency for women to show greater environmental concern is also well-documented (Clements, 2012; Hunter et al., 2004; Zelezny et al., 2000), and suggestions for this increased concern include women's roles as caregivers, the expectation on them to show compassion, and the importance they place on altruism and the maintenance of life (as reviewed in Hunter et al., 2004). This difference in environmental attitudes may emerge as a higher WTP amongst women in stated preference surveys (e.g. Carlsson et al., 2003; Rolfe and Bennet, 2009) although the effect of gender is regularly insignificant (e.g. Boxall et al., 2012; Adaman et al, 2011; Barr and Mouranto, 2009), or men may show a higher WTP for certain environmental benefits, particularly in relation to use values (Dupont, 2004; Tseng and Chen, 2008).

Expert knowledge

One of the variables that was not significant in the model was whether the respondent was an expert in marine science. Other studies have shown that increasing the information available to the respondent increases their WTP (Bergstrom and Stoll, 1990) and that level of experience also affects WTP (Cameron and Englin, 1997), so it was expected that expert knowledge would influence WTP. This does not appear to be the case, however. It has been argued that the requirement for extensive prior knowledge is overstated, as people rarely spend prolonged periods (i.e. in excess of time spent learning in CV exercise) familiarising themselves with new market goods prior to purchase (Carson et al., 2001). The findings from this study support to argument that experience is not prerequisite for making meaningful economic choices about environmental goods.

Use of the affected ecosystem

There is a general expectation that the use a respondent (or members of his household) makes of an environmental good or service will influence WTP, and this has been demonstrated in situations such as WTP for recreational fishing opportunities (Toivonen et al., 2004) and for the wider conservation of fish stocks (Baker and Pierce, 1997). Few activities take place directly on the mudflats, due in part to the difficulties of traversing them, although people may experience mudflats more indirectly through walking or cycling along the banks of the estuary. Respondents were asked about their use of estuarine environments through their participation in watersports, walking or cycling on coastal and river paths, birdwatching, and angling or crabbing.

None of these variables were significant in the model, but some evidence was found, however, that recreational use of estuarine environments had an influence on WTP through shaping environmental attitudes. Birdwatching and walking or cycling on coastal and river paths were both statistically significant variables in predicting concern about mudflat loss as measured by the AHP weight, although the model was quite weak.

The results from the choice experiment suggested more strongly that use of the environment around mudflats was an important factor in determining values for habitat loss. The interaction terms between habitat loss and both watersports and walking/cycling on coast/river paths were significant, and suggested that those who use the coastal environment in this way are particularly unwilling to see a loss of habitat.

However, the sample size used in the choice experiment may not be sufficient to draw robust conclusions on the influence of social and demographic factors, because factors such as gender did not show the expected statistical significance. Reducing the sample size for the contingent valuation to 143 individuals (in order to model only the responses from North Devon respondent data for comparison with the choice experiment) produced a reduced suite of significant socio-economic variables compared to the full sample (284 individuals) and, contrary to economic theory, income was not one of these.

Pro-environmental attitude

The use of respondent attitudes as a means of interpreting valuation responses was one of the recommendations of the NOAA Panel on Contingent Valuation (Arrow et al., 1993), as conformity to theoretical expectations is a useful way to verify the credibility of the results obtained. It has been shown that the strength of environmental concern can be more important in determining WTP than a respondent's familiarity with the good or service in question (Moore et al. 2011; Turpie, 2003).

A dummy for membership of a conservation organisation is commonly used to assess a respondent's level of environmental concern, and that was one approach taken in this study. Conservation group membership was not, however, a significant predictor of WTP in this research, or in several other studies (e.g.Barr and Mourato, 2009; Ressurreicão et al., 2011; Ransom and Mangi, 2010; Togridou et al., 2006). It appears common, therefore, for studies to fail to show a link between membership of a conservation organisation and WTP. It is possible that these studies lack internal consistency and their results should be treated with caution. Alternatively, conservation group membership may be a poor measure of environmental concern, as it does not reflect the wide range of individual situations and perspectives (Kotchen and Reiling, 2000).

Such dummies are perhaps unreliable predictors of WTP because they may say more about the respondent's feelings about belonging to groups (or to charitable donation or to activism) than about her attitude to the environmental good being valued. Dummies reflecting actual environmental behaviour are perhaps better indicators of pro-environmental attitudes; interest in recycling (Ransom and Mangi, 2010) and usage of environmentally-friendly goods (Ressurreicão et al., 2011) have both been shown to be significant predictors of WTP. However, these are less widely employed than questions about conservation group membership, so it is more difficult to determine whether, in general, they do perform better.

Alternative approaches to quantifying pro-environmental attitudes include asking the respondent to express, on a Likert scale, the level of his concern about environmental issues. This technique was also employed in this research, using questions on climate change. Strong agreement that climate change would be a problem in the future was found to be a significant explanatory variable for WTP. It is unlikely that this represented anything other than an indication of pro-environmental attitude, as the carbon emissions reduction was the same in both barrage scenarios so there is no obvious reason why attitude to energy issues should influence WTP in other ways.

The expected result was obtained in this study, but the responses given to Likert scale questions do not always have a significant influence on WTP (Jones et al., 2011). They may produce unreliable data because it may be easy for respondents to overstate their level of environmental concern when presented with simple statements about the valuation scenario.

The use of a comprehensive range of general attitudinal questions, which include internal tests for consistency, may be a more robust approach to assessing levels of environmental concern. The New Environmental Paradigm (NEP) developed by Dunlap and Van Liere (1978) and updated as the New Ecological Paradigm by Dunlap et al. (2000) is one example of a comprehensive assessment of environmental attitudes. It comprises 15 questions with a five-point answer scale, and has been widely used, with over 425 citations in the Web of Knowledge database.

Use of the NEP is not common in empirical contingent valuation of environmental goods, and when it is employed this may be purely for the purpose of providing descriptive statistics about the sample population. Where the NEP score is modelled as an explanatory variable, there again appears to be no consistent relationship with WTP for the environmental good. The NEP score has been shown to be a significant predictor of increasing WTP (Kotchen and Reiling, 2000; Ito et al., 2010) but has also proven insignificant or inconsistent in other WTP models (Moon and Griffith, 2011; Szabo, 2011; Milton and Scrogin, 2006).

Researchers employing the NEP in contingent valuation frequently reduce Dunlap et al.'s (2000) full set of 15 questions, often to as few as five to eight statements. This is apparent both with its application in contingent valuation (Wallmo and Lew, 2011; Mjelde et al. 2012; Moon and Griffith, 2011; Solomon et al., 2004; Ito et al., 2010) and in its use in the wider social sciences; only 58% of the 69 studies featuring in a meta-analysis used the complete set of questions (Hawcroft and Milfont, 2011). Reducing the number of questions may affect the validity of the NEP score (Hawcroft and Milfont, 2011). This does not appear to entirely explain its inconsistent performance as an indicator of WTP, as studies using the compete NEP have still found no significant link to WTP (Szabo, 2011).

This evidence from the literature suggests that there are problems associated with the measures currently used to evaluate a respondent's level of concern for the environment. An alternative, and novel, approach was also employed in this study in an attempt to quantify the respondent's concern for mudflat loss. The relative importance of mudflat loss compared to three other barrage parameters was assessed using the Analytic Hierarchy Process (AHP), which provided an AHP weight for mudflat loss for each respondent. This weight proved to be a significant explanatory variable for WTP, and showed the expected positive sign. The AHP may be a better predictor of WTP because it evaluates specific concern for the good in question (mudflats) as opposed to the environment more generally.

AHP has been used before with economic valuation, but usually as a means of verifying the weights obtained in choice experiments, or further exploring trade-offs or respondent preferences (Moran et al., 2007; Martin-Ortega and Berbel, 2010; Columbo et al., 2009; Kallas et al., 2007). It has also been employed to disaggregate use and non-use values from the total WTP (Wattage and Mardle, 2008). AHP weights have not, to the author's knowledge, previously been used as variables in econometric models of WTP. It would be interesting to repeat the use of AHP in this way, to ascertain the potential of AHP weight as a reliable measure of pro-environmental attitude in contingent valuation, and so confirm the finding of this research.

8.5 Consistency in willingness to pay across elicitation methods

A comparison between WTP elicited under the contingent valuation and the choice experiment can be made by considering the WTP elicited from the North Devon respondents (as the choice experiment considered only this group). The contingent valuation suggested that the mean value to residents of North Devon to protect 70ha of estuarine mudflat in the Taw Torridge was £28.17 (S.E. £3.19). This was not significantly different the implicit price obtained from the choice experiment (£17.76, S.E. £7.60), although there was a large standard error on the latter.

However, some variation in the elicited value is to be expected given the decision frames employed. The choice experiment model was based the difference between current and changed levels of mudflat provision while the contingent valuation considered changes in provision after some loss of habitat had already occurred (resulting from the baseline barrage). From the conventional assumption of a concave utility function (with diminishing marginal utility) over the provision of a normal good, these differences would be expected to lead to inequalities in WTP, *ceteris paribus*

The contingent valuation defined three barrage schemes, which would result in different levels of habitat loss compared to current provison, P: Barrage A (P–210), Barrage B (P–140), and Barrage C (P–70). The WTP stated above (£28.17) refers to $CV = u(B) - u(A)$ (as illustrated in Figure 36). The implicit price derived from the choice experiment also considers a change in mudflat area of 70ha, but this value (CE = £17.76) lies further to the right on the utility curve. Therefore, obtaining a lower WTP in the choice experiment would be entirely consistent with theoretical expectation. Both the contingent valuation and, in particular, the choice experiment consider the upper part of the utility curve (close to the maximum mudflat provision), where the gradient is shallow, and so a relatively small difference between the values elicited by the two methods is to be expected. That there was no statistical significance attributable to the difference in WTP between the two methods in this study is also potentially a factor of the relatively small sample size in the choice experiment.

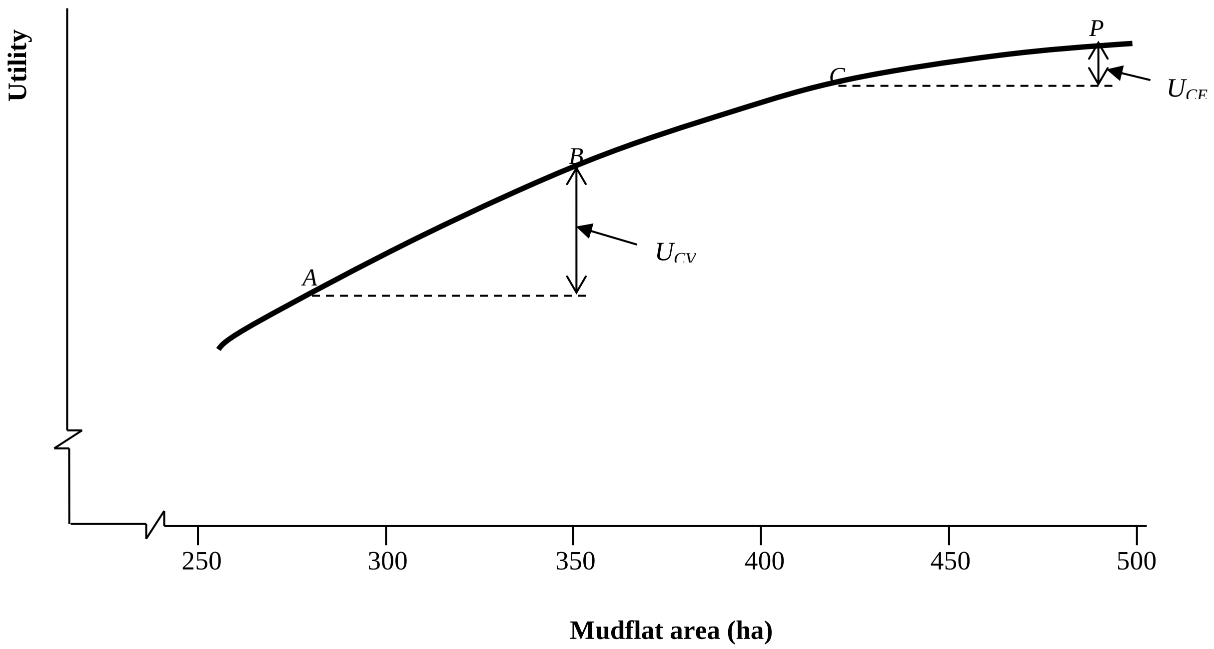

Figure 36. An illustrative utility function for the availability of mudflat in the Taw Torridge

The effect on WTP of different elicitation formats has been examined in the literature, but there appear to be few studies that compare discrete choice experiments with contingent valuation. Those that have do not show a consistent trend, for example there was strong agreement between the two methods for the value to preserve cultural heritage (Tuan and Navrud, 2007) but the willingness to pay for benefits expected under the Water Framework Directive was significantly higher when a choice experiment was used compared to a payment card (Metcalfe et al., 2012). A study of the social value of the charitable sector found that choice experiments produced higher values than contingent valuation when the question referred to the sector as a whole, but lower values when it concerned a specific subset of the sector (Foster and Mourato, 2003).

Reasons postulated for variation with elicitation method include the greater opportunity for strategic behaviour when using the payment card approach (Metcalfe et al., 2012) and the greater sensitivity to scope exhibited by choice experiment approaches (Foster and Mourato, 2003). The research presented here also illustrates that differences between WTP may depend on the framing of different scenarios, and hence may be entirely consistent with theoretical expectations. The variation obtained within the studies referred to above highlights the need for multiple studies, using different methods, in order to obtain robust welfare estimates.

8.6 Relative preferences for tidal barrage attributes

Respondents' attitudes to barrage attributes

Eliciting WTP to pay to reduce estuarine mudflat loss was the central focus of this thesis, but the study also explored how members of the public perceive certain other costs and benefits of tidal barrage schemes. Initially, the Analytic Hierarchy Process (AHP) was used to evaluate these trade-offs, and the weights elicited indicated that cost was not the primary factor motivating most respondents' preferences for barrage schemes. Respondents appeared to have a greater concern for how certain environmental and social parameters will be affected, particularly the loss of coastal mudflats and the enhanced flood protection provided by the barrage. This supports similar findings from a survey of public attitudes to the Severn barrage, in which 56% of respondents selected the negative impact on habitats as the most important disadvantage of a barrage ahead of the potential high cost (chosen by 17% of the sample) (Opinion Leader, 2007). Not all of the potential social or economic advantages outweighed the cost consideration, however: the improved potential for watersports was unimportant to most respondents in this survey.

AHP Consistency

It utilising the AHP, Saaty (2008) advocates considering the consistency ratio, which compares the weights given by the respondent to those generated randomly. Not all authors using the AHP report their treatment of the consistency ratio issue (e.g. Ananda and Herath, 2008; Duke and Aull-Hyde, 2002), but some (e.g. Shen et al, 2010; Innes and Pascoe, 2010) have followed Saaty's guidance and report analyses excluding any responses for which the CR exceeds 0.1. This practice is not universal however, and other researchers set their own CR thresholds. Himes (2007), for example, decided that it was acceptable to increase the CR threshold to 0.2, to account for the complexity of the choices facing respondents and the higher levels of inconsistency that could be expected as a result.

Himes' (2007) decision resulted in the exclusion of 26% of respondents, even with the raised CR threshold. Within this study, removing those with a CR greater than 0.1 would exclude 77% of Wellington respondents and 64% of North Devon respondents. At the 0.2 level, 64% and 48% of respondents from each site, respectively, would still be excluded. A similar proportion would also be excluded from the expert and other academic samples. Ishizaka et al. (2011) also found a similar level of inconsistency: only 31% of their sample had a consistency ratio of 0.1 or less, and this was in a fairly simple experiment about choosing chocolate – a scenario not unfamiliar to respondents. In another example, only 49% of responses from Apostolou and Hassell's (1993) survey of professional accountants had a consistency ratio of 0.1 or less.

It appears that inconsistency, by Saaty's definition, is common to many respondents. The acceptability of excluding large numbers of participants because they do not conform to a mathematical definition of an ideal response is therefore questionable, and the applicability of the CR should be challenged.

In considering this issue, authors have adjusted matrices to produce more consistent responses, and have concluded that this action does not significantly improve the validity of the AHP results (Linares, 2009). In one such assessment, the maximum deviation between the original weighting and that of the adjusted matrix was much lower than ±0.01 (Calizaya et al., 2010). Even in studies where inconsistency is high, AHP weights still produce results close to those of direct ranking methods (Ishizaka et al. 2011). The issue of consistency, by Saaty's definition, does not therefore appear to invalidate AHP as a decision support tool.

Further investigation is required into the reliability of the CR: it has been criticised for failing to provide a clear interpretation of consistency (Monsuur, 1997); intransitive responses can produce a CR below Saaty's threshold (Bana e Costa et al., 2008); and respondents who lack firm preferences and repeatedly change their minds are not predicted by inconsistency in AHP weights (Ishizaka et al., 2011).

The mathematical foundation of the CR threshold has also been questioned, and it has been shown that large CRs are inherent when a 9-point scale is used, particularly with larger matrices (Murphy, 1993). The use of randomly generated matrices as the comparator has also been criticised, as they do not take account of the decision situation (Monsuur, 1997). The complexity of the decision is likely to influence consistency (Gass, 1998; Calizaya et al. 2010) as is the wider survey scenario given that preference may be context-dependent (Tversky and Thaler, 1990).

This research does suggest that respondents' familiarity with the attributes being considered may influence the consistency of their preferences, as those living or working near the coast (and therefore likely to be more familiar with the coastal issues in question) provided more consistent matrices than respondents based inland. A meta-analysis of results from environmental AHP studies to determine a range of acceptability for CRs could be a useful step in progressing this debate.

Comparing barrage attribute weightings between the AHP and the Choice Experiment

The AHP asks respondents to weight the importance of the different barrage attributes in the absence of defined prices, while cost is an integral part of the choice experiment, allowing the relative implicit price of each attribute to be determined. In the AHP, there was no significant difference between the weighting for mudflat loss and that for the flood protection provided by a barrage. However, in the choice experiment the WTP for flood protection for 500 homes was almost four times higher than that to reduce mudflat loss by 70ha. This apparent inconsistency between the methods may result from the way the AHP was presented: it concerned attitudes in general rather than to a specific scenario. Had the AHP included quantities for the attributes (and therefore more closely matched the choice experiment exercise) it is possible that a different result would have been obtained.

Where attributes are measured on different scales, the validity of directly comparing the elicited monetary values is questionable (Christie and Rayment, 2012). Such a comparison does, however, provide information about the relative value of attributes under the explicit scenario described by the choice experiment. In this case, the WTP derived by the choice experiment for additional renewable energy sufficient to power an extra 6,500 homes was also higher than to prevent mudflat loss (by a factor of nearly three), indicating that respondents were prepared to trade-off a degree of local ecosystem loss in order to obtain the benefits of increased renewable energy. Respondents' motivations for valuing an increase in renewable energy were not explored. The scenario did not confine respondents to considering only carbon emissions, and so their WTP is likely to represent a bundle of values including, for example, job creation and energy security as well as any wish to mitigate the global environmental issue of climate change.

The choice experiment results suggest that respondents had a strong preference for local social gains over environmental losses (local and global): flood protection had a higher implicit price than both mudflat loss and the quantity of renewable energy produced. There is evidence to support this finding that environmental issues are not the main concern for most members of the public: only 19% of respondents to a survey of environmental opinion prioritised the environment over other issues of concern (Environment Opinion Survey (1990), cited in Dunlap and Scarce (1991)). More recently, findings of the General Social Survey were presented showing that no more than 15% of survey respondents in any of 32 countries considered the environment to be their country's most pressing concern, ranking it below issues such as the economy, health, education, poverty and crime (Smith, 2013). This survey also suggested that climate change was the highest ranked environmental concern amongst respondents from Britain and most other western European nations included in the survey (Smith, 2013), supporting the finding from this study that climate change is prioritised more highly than local habitat losses.

The motivation behind environmental concern has been explored, with Stern and Dietz (1994) suggesting three types of value. Egoistic values drive people to consider how the costs or benefits of environmental protection affect them personally, while social-altruistic values reflect a sense of moral obligation that causes people to act when they believe adverse consequences are likely to occur to others. Finally, biospheric values lead to judgements based on the implication of human action on the ecosystem. Schultz (2001) provides empirical evidence to support this theory that environmental attitudes are shaped by concern for the consequences to self, other people and the biosphere. Levels of concern are also shaped by a person's awareness of the consequences of environmental change to objects he values (Schultz, 2001). The relative implicit prices derived in the choice experiment may therefore reflect the likelihood that respondents are more familiar with the potential consequences of climate change for themselves and others, and may perceive them as likely to have more significant impact than local-scale habitat loss.

8.7 Policy implications of the research

Transferability

Benefits transfer (taking a value obtained in one situation and applying it to another) is commonly used to value ecosystem services where insufficient resources exist to conduct empirical valuations. During the feasibility study in 2010, the loss of habitat expected under various Severn Barrage scenarios was valued using this method (Hime and Ozdemiroglu, 2010). It is therefore possible that the values obtained in this research will be utilised in other studies, especially given the lack of empirical valuations for UK estuarine mudflats. However, there are significant constraints on the suitability of this data for benefits transfer, not least that an improved understanding of distance decay effects is required before the value can be aggregated across the wider population.

Another constraint is that taking the average WTP for each of the two contingent scenarios shows that the relationship between WTP and area of habitat lost is not linear. This is to be expected, but there are insufficient data points to construct a curve from which the actual relationship between WTP and area could be derived, or even to determine the range of mudflat area over which the value obtained is valid. Therefore, the WTP elicited in this study should not be converted to a per hectare value, and should only be applied to reduction in mudflat loss of 70ha. This limits its applicability to estuaries such as the Mersey or the Severn, where habitat loss would be one to two orders of magnitude greater. Also, the study concerned a single estuary, and so there is no evidence that the value obtained in this study would be applicable in other locations, as the unique characteristics of each site may have a significant effect on WTP. The Severn estuary, for example, is an important overwintering site for migratory birds, which is recognised by designations under the Habitats and Birds Directives, and this may influence WTP.

Use in Cost Benefit Analysis

The Environmental Benefits Assessment (Chapter 3) illustrated the potential for a tidal barrage to negatively impact on a range of environmental benefits including food provision, raw materials, most recreational opportunities, cultural heritage, wellbeing, water quality and some aspects of flood protection. Conversely, a barrage may increase the supply of other benefits through new opportunities for education, research and some recreational activities, and by enhancing other aspects of flood protection. One technique to determine which, if any, of a range of barrage schemes should go ahead would be to use cost benefit analysis to evaluate the different options.

Conducting a full cost benefit analysis for a barrage in the Taw Torridge is beyond the scope of this study, not least because in the absence of a detailed feasibility study, there is no information available on the quantities of construction materials, generating technology and labour that would be required to construct a barrage and so these costs are unknown. Potential wider economic benefits, such as improved transport links or job creation, have also not been quantified. Similarly, there has been no quantitative assessment of the scale of likely impact on environmental parameters such as migratory fish and cultural benefits. While a full cost benefit analysis cannot be attempted, it is possible to use a cost benefit valuation approach when considering certain trade-offs that would need to be made in designing a barrage scheme in the Taw Torridge. In particular, bearing in mind the original motivation for this research (see Chapter 1), to evaluate how the local environmental impact of habitat loss compares to the national and global scale benefits of reduced carbon dioxide emissions.

As described in Chapter 5, the most plausible location for a barrage in the Taw Torridge would be crossing the Taw at Crow Point near the confluence of the two estuaries, with a possible alternative site about 2km upstream, just to the east of Isley Marsh. The barrages would be comparable in size and the two potential sites are close together, and so it can be assumed that construction costs and economic benefits such as job creation and transport links would be very similar. In terms of the impacts on environmental benefits, either barrage would be a large structure and would create an obstruction across the entire width of the estuary and so the impacts on benefits related to fish movements, vessel passage and cultural services such as education, research, heritage and wellbeing would again be broadly similar between the different barrage schemes. Where the alternative schemes would differ more significantly would be in terms of the impacts on carbon emissions, the loss of intertidal habitat, flood protection, water quality and the increased potential for watersports upstream of the barrage (see Table 6, an extract from which is reproduced below).

Table 6. The attributes of the different barrage operating modes at the Crow Point and Isley Marsh sites

Location	**Crow Point**		**Isley Marsh**	
Scheme type	**Ebb-only**	**Two-way**	**Ebb-only**	**Two-way**
Carbon emissions reduction (tonnes/yr)	62,000	50,000	43,000	35,000
Area of saltmarsh & mudflat impacted (ha)	220	140	120	80
Number of homes protected from flooding	2,400	2,400	1,900	1,900
Deterioration in water quality	High	Moderate	High	Moderate
Improvement in upstream watersports potential	High	Moderate	High	Moderate

The changes watersports potential cannot be valued because current levels of recreation have not been adequately quantified, and there is no informatio about the extent to which the theoretic improvement in potential would be realised as actual changes in watersports activity. However, valuation can be attempted for the changes in carbon emissions reduction, habitat loss, flood protection and water quality. Therefore, an economic assessment can be made for these attributes to compare the alternative barrage designs to the baseline scheme of an ebb-only barrage at Crow Point.

In valuing carbon emissions, the UK Government has moved away from methods that value the damage caused to those based on the cost of mitigation (DECC, 2009c). Current policy is to use the traded price of carbon for emissions reductions from electricity generation, as this sector is included within the European Union Emissions Trading Scheme (DECC, 2009c). In 2011 (the period during which WTP was elicited in this study), the traded price of carbon ranged from £6 to £17 per tonne, with a central value of £13 per tonne (DECC, 2011). Extending this cost of mitigation approach to flood protection suggests that improving flood defences to protect Braunton would cost £100,000 (Environment Agency, 2013)

The WTP from the contingent valuation (£26.17) remains an appropriate for the prevention an 80ha habitat loss, and WTP to reduce habitat loss by 140ha (£36.27) was elicited during the scope sensitivity assessment. This could potentially overestimate WTP as only those expressing a positive WTP in the first contingent scenario were questioned about scope, but it remains close to the implicit price suggested by the choice experiment (£35.40). In determining the total value of the habitat loss reduction, the elicited WTP must be aggregated across the relevant population. The respondent sample used in this study suggests that the WTP can only be reliably aggregated across the population who live relatively close to the Taw Torridge, as distance decay was not evaluated adequately to permit aggregation at a larger scale. The survey did show that WTP is maintained over distances of 50-60 miles from the estuary. The exact number of households within this radius is not known, but the area approximates that of Devon and so the population of Devon (0.4 million households (ONS, 2011)) can be used as a reasonable indicator.

It seems most appropriate to consider water quality in the context of the Water Framework Directive, which would require the Taw Torridge to meet the required standards for Good Environmental Status. This was the context for a study which elicited values for improving the aesthetic appearance of a river in terms of its water clarity, plant growth, visual pollution and odour (Stithou et al., 2012), which suggested that households within the catchment of the affected river would be willing to pay £35.44 per year and £15.62 for " a lot" and "some" improvement respectively. The Taw Torridge catchment area matches closely to the administrative boundaries of the North Devon and Torridge local authorities, which contain almost 68,000 households (ONS, 2011). Aggregating the WTP elicited by Stithou et al. (2012) across this area suggests a WTP of £2.4 million and £1.1 million for the two levels of water quality improvement. The potential for a two-way barrage to reduce water quality deterioration from 'high' to 'moderate' can be assumed to result in a monetary value that is the difference between these two values.

Comparing the economic values of the changes to the environmental attributes considered (Table 41) suggests that the benefits of reducing impacts on habitats and water quality are considerably larger than the costs of the lost potential for carbon emissions reduction and flood protection. This suggests that there is an economic argument for mitigating the environmental impacts of tidal barrages by considering alternative schemes.

Table 41. The change in selected costs and benefits for alternative tidal range schemes in the Taw Torridge estuary, compared to baseline case of an ebb-only barrage at Crow Point

Location	**Crow Point**	**Isley Marsh**	
Scheme type	**Two-way**	**Ebb-only**	**Two-way**
Reduction in carbon emissions	-156,000	-247,000	-351,000
Reduction in mudflat impacted	10,468,000	10,468,000	14,508,000
Reduction in flood protection	0	-100,000	-100,000
Deterioration in water quality	1,348,000	0	1,348,000
TOTAL	**11,660,000**	**10,121,000**	**15,405,000**

However, the outcome of this type of economic comparison can vary considerably depending on the assumptions and approaches used. In particular, there can be very significant differences in values between social cost and cost of mitigation approaches. For example, a recent model produced an upper estimate of £66.5 per tonne for the social cost of carbon (Anthoff and Tol, 2013), more than five times the traded price (DECC, 2011). Even larger differences occur for flood protection. The WTP elicited by the choice experiment in this study and aggregated across the population of Devon suggests flood protection for Braunton has a value of £31 million, far in excess of the £100,000 from a cost of mitigation approach.

Also, this comparison above (Table 41) is based on a single year, when tidal barrages are known to operate for at least 40 years (based on the lifespan to date of the La Rance barrage) and could have a lifespan of 120 years (SDC, 2007). A better comparison of the costs and benefits should consider this temporal element, but the accuracy of values that would be derived from attempting this is questionable. In the case of carbon emissions, the market price of carbon based on the costs of abatement has been predicted for the period to 2100, using models to evaluate different emissions scenarios (DECC, 2009c; 2011). However, in 2011, DECC predicted a central traded carbon value of £16 for 2014, but then in 2013 substantially revised this estimate to £3.59 (DECC, 2013b) suggesting that the values given for even the short-term future are not reliable.

There are also issues with projecting WTP into the future. Arguably, WTP in this study should have been elicited as a one-off payment due to the effectively irreversible nature of the impact on habitats, but the question was not asked in this way. Instead, WTP was elicited as an annual payment, but length of time over which respondents were prepared to pay was not explicitly determined. Research suggests that WTP is quite robust over a period up to about five years (Bliem et al., 2012; Liebe et al., 2012; Skourtos et al., 2010), but that over two decades factors affecting valuation and mean WTP (such as income levels) can change significantly (Boman et al, 2011; Skourtos et al., 2010).

Aggregation also affects the total value of the mudflats derived. This value would be correspondingly higher if the wider regional or national population have a positive WTP to reduce habitat loss in the Taw Torridge. If the WTP remains valid for the 2.3 million households in the South West (ONS, 2011), or if, on average, the 26.3 million households in the UK (ONS, 2012) have a WTP of at least 10% of that of local people, then the habitat value exceeds £300 million, and mitigation by changing the operating mode or reducing the size of the barrage becomes justifiable. It is not impossible that such WTP does exist within the wider population. Bateman and Langford (1997) suggest that WTP for a national park amongst respondents living at least 360km from the park's location remains at 37% of that for those living within 40km, with an average for all respondents across the UK equating to 55% of local residents' WTP. Similarly, Pate and Loomis (1997) show that those living over 1,500km from a wetland have a mean WTP for its improvement that is 46% of that expressed by local residents.

8.8 Summary

This study has obtained a value for UK estuarine intertidal mudflats. The econometric model fulfils expectations under economic theory, as it demonstrates that WTP to reduce mudflat loss is influenced by income and by a respondent's level of environmental concern. The implicit price for habitat loss derived through the choice experiment was not significantly different from the WTP obtained using the contingent valuation. This agreement between the two methods gives confidence in the robustness of the valuation result.

This study has also shown that the Analytic Hierarchy Process (AHP) may enhance contingent valuation by providing an effective measure of a respondent's level of concern for the environmental good being valued. This level of concern may also influence whether a respondent's WTP shows scope sensitivity. The AHP also demonstrated that respondents have concerns about the social and environmental consequences of barrages. When presented with a selection of tidal barrage costs and benefits, survey respondents placed particular importance on the loss of costal mudflats and the potential flood protection advantages ahead of the increased cost of electricity and the potential watersports gain. The relative implicit prices obtained from the choice experiment suggest a hierarchy of value with local social benefits being valued more highly then global environmental benefits, which in turn are valued more highly than local environmental benefits. However, the attributes were all measured on different scales, and so the validity of making a direct comparison between them is questionable.

Use of estuarine environments did not appear to directly influence WTP to any significant extent, although time spent undertaking recreational activities within coastal and estuarine environments does appear to influence levels of environmental concern, and hence has an indirect effect on WTP. WTP values do not appear to decline over a distance of 50 miles from the affected site, and may actually increase, potentially because non-resident respondents may consider the area as somewhere special for their own leisure and enjoyment.

The results have limited transferability to other situations, as the area of habitat for which the WTP is valid cannot be stated categorically. Without a greater understanding of the change in WTP as distance from the site increases, the values elicited in this research cannot be assumed to hold across the UK. Without this understanding of WTP regionally and nationally, and also how prices and values change over the lifespan of a barrage, no unequivocal conclusion can be drawn about whether mitigation schemes can be justified on the grounds that the value of the habitat protected outweighs the carbon savings foregone when the energy output of the scheme is reduced. Further empirical work is needed to address these issues, and comprehensive cost-benefit analysis is required to properly assess the complex trade-offs involved in barrage construction.

9 Conclusions

9.1 Policy context

The UK Government has committed to legally-binding targets for carbon emissions reduction, the fulfilment of which will require significant deployment of renewable energy. Tidal energy has advantages over other renewables including wind and wave power as it is independent of weather conditions and is predictable over the long term. Tidal barrages have additional advantages in that they can produce significant amounts of energy, have a long lifespan and use proven technologies. At a local level, barrages can also provide opportunities for employment, transport links and tourism, and improved conditions for watersports. However, barrages may cause severe environmental impacts, particularly the loss of intertidal habitat, deterioration in water quality, and impediment to the passage of migratory fish. Alternative technologies or barrage operating modes have been proposed to mitigate these impacts, but to date barrage feasibility studies have rejected such schemes because the predicted unit cost of electricity is not competitive.

However, the economic assessments within these feasibility assessments are incomplete, as the value of the environmental changes has not been taken into account. Economic valuation of environmental goods and services provides a mechanism to address questions such as whether the value of the habitat and species protected justifies the increased cost of mitigating environmental impacts, and whether the global environmental benefits of carbon emission reduction outweigh the local environmental costs.

Tidal barrages have the potential to impact upon a wide range of environmental goods and services, but there is a lack of empirical economic data for most of these. A low degree of confidence could therefore be attributed to the findings of an economic assessment that attempts to account for all the diverse costs and benefits associated with barrages. Instead of taking a cost benefit analysis approach, this research aimed to further relevant knowledge by providing an empirical economic value for one environmental component: estuarine intertidal mudflats. The loss of mudflats is considered one of the most significant environmental impacts of tidal barrages, and reducing it is often the main purpose of proposed mitigation measures. Also, there is almost no published information about the values held by the public for these habitats.

9.2 Applying an ecosystem services approach to complement environmental impact assessment

The purpose of this component of the research was to explore at a practical level how the ecosystem services approach could be implemented to support local planning. This contributed to filling an important gap as empirical local-scale studies of marine ecosystem services rarely attempt to assess more than one service at a time. More comprehensive assessments, such as that attempted in this study, are urgently required in order provide information as to how the Environmental Impact Assessments (EIAs) process could be brought more in line with an ecosystem services approach: a balanced judgment on a specific local development must take account of all the benefits that arise in an area and the potential impact of the intervention upon them, as is the case EIAs.

The case study in the Taw Torridge estuary demonstrated that the proposed Environmental Benefits Assessment (EBA) provides a systematic method by which to approach assessment of the implications of local scale developments on a broad suite of environmental benefits, and so provides a step forward in bringing EIAs more closely into line with the concepts of ecosystem service assessments. However, the EBA approach also illustrated that focusing entirely on the endpoint – benefits – provides no information about how the underlying services may be impacted, and hence how the ongoing delivery of the expected benefits may be threatened. Therefore, benefits should not be considered in isolation, and the methodology should be extended to include indicators of the underlying ecosystem services that are essential for the continued delivery of the benefits described. The EBA also demonstrated that there are some instances for which only the service, and not the benefit, should be quantified. For example, carbon sequestration is a service that provides an appropriately regulated climate, but there is no tangible metric by which to define this benefit. It is relatively straightforward, however, to determine the level of carbon sequestration, using objective metrics, and so this can be used as a proxy for the benefit of an acceptable climate.

Climate regulation is also an example of how a methodology that considers strictly benefits alone may not deal adequately with issues of scale. The impact on the climate of an individual local-scale development will always be effectively nil. That does not mean the issue of climate regulation can be ignored, because the cumulative effects of multiple small developments have a demonstrably large impact. Measuring changes in the level of carbon sequestration provides a mechanism to record the relative impact of the development on climate regulation.

The EBA approach also demonstrates the challenges in identifying appropriate metrics for the objective quantification of cultural benefits. It is important that cultural services remain within an EBA inventory, to ensure that any impacts upon them are considered and mitigation suggested. The difficulties in quantification suggest, on a pragmatic level, that certain cultural services should instead be assessed in more qualitative terms, using wider social science methods. However, separating environmental benefits according to whether they are amenable to quantification brings the risk that the non-quantified services will continue to be overlooked in management decisions, suggesting that research into quantifiable indicators for cultural services is a priority. Conducting the EBA for the Taw Torridge specifically also highlighted the particular lack of information on cultural benefits and non-use values for the estuary, supporting the decision to focus on a stated preference study to value of intertidal mudflats during the empirical phase of the research.

9.3 Determining a monetary value for welfare changes associated with changes in mudflat provision

This research provides what is thought to be the first empirical study of the value of UK estuarine mudflats; demonstrates the complementary use of two stated preference methods; and introduces a novel application of the Analytic Hierarchy Process (AHP) to support environmental valuation. It also provides some broader insights into preferences for different costs and benefits of tidal barrages.

A positive willingness to pay was elicited by the research, showing that members of the public do derive benefits from estuarine mudflats, to the extent that they are willing to sacrifice income in order to reduce habitat loss. The WTP elicited in the choice experiment was not significantly different from that elicited by the contingent valuation, suggesting that the value was a robust reflection of WTP. The scenarios described by the contingent valuation and the choice experiment concerned different parts of the utility curve, due to slight differences in the framing, so some difference in the WTP elicited by each method was to be expected. The results obtained in this study suggested consistency with the theoretical expectation that the WTP obtained in the choice experiment would be lower. The difference was not statistically significant, however, potentially due to the small sample size.

9.4 The validity and reliability of the elicited values

General economic theory

The findings of this research demonstrated validity with regard to the level of provision of the good in that there was a significant difference in WTP for 70ha and 140ha of mudflat loss. An important additional contribution of the research was the relationship that was observed between the importance of mudflats to the respondent (as measured by the AHP weight) and the likelihood of his stated WTP showing sensitivity to scope. This may indicate that people with a particular concern for the environmental good in question are more likely to the express a WTP for the good itself, while those who are less concerned may be more likely to be paying for the “warm glow” of supporting a good cause.

The relationship between distance from the affected site and WTP was not evaluated adequately, as there was insufficient geographical separation between the Taw Torridge and the group of non-local respondents. However, the research did indicate that a small 'inverse distance decay' effect may occur when the WTP of those who are not resident near, but are very familiar with, the affected site is elicited. The perception of a site as special (i.e. a holiday destination) rather than everyday may be a factor in this finding, although it may also relate to the reduced sample size, as this factor only became significant when protesters were excluded from the sample.

The influence of personal characteristics

The factors with the most influence on WTP were income, gender, and level of environmental concern, which are concurrent with expectations from economic theory. These influential factors were consistent across five regression and tobit models, and remained significant whether protest bids were included in, or excluded from, the sample, demonstrating the robustness of the estimates.

The AHP proved to be a useful technique for quantifying levels of environmental concern, performing better than membership of a conservation organisation. The AHP weight measured the importance to the respondent of mudflat loss specifically (whereas conservation group membership lacks this direct link), which may explain the strength of the relationship. The AHP weight was influenced by time spent walking or cycling near the coast and birdwatching. These variables had no significant influence on WTP directly, but appear to be important in shaping environmental attitudes. Expertise in marine science was not a significant predictor of WTP, refuting the argument that a detailed knowledge of environmental goods is necessary before they can be valued. The link between participation in certain coastal activities, level of environmental concern (as measured by the AHP weight) and WTP suggests that exposure to, rather than understanding of, environmental goods influences WTP.

9.5 Limitations, and applications, of the values obtained

A particular limitation of the research is that it considered only two levels of habitat loss, so there are insufficient data points to determine the range of mudflat area for which the value is valid. Also, the research considered the issue of distance decay, but only through interviewing those resident 50 miles from the case study site, who, it transpired, had a relatively high degree of familiarity with the study site. It would be unwise to extrapolate findings from this sample group in order to make assumptions about the values held by the wider population, the vast majority of whom live much further from the site and are less familiar with it.

The limitations on the aggregation and transferability of the WTP limit the conclusions that can be drawn about how the value of habitat loss compares with the other attributes of different barrage schemes, such as the changes in carbon emission reduction. The conclusions of any cost benefit analysis of different barrage schemes are also affected by the assumptions made about the appropriate approach (cost of abatement versus social cost, for example) and any predictions about values made for the long lifespan of a barrage.

9.6 Policy recommendations

This research demonstrates that intertidal mudflats within the Taw Torridge have considerable value to members of the public living within 60 miles of the estuary. The economic value of even a relatively small area of mudflat (70ha) is at least £10 million, and potentially considerably higher, assuming at least some non-use values exist amongst the wider population. This suggests that it is important to take adequate account to this monetary value when undertaking cost benefit analysis for developments such as tidal barrage (or, for example, marinas) that would impact upon this habitat.

9.7 Further research

The limitations of this work could be addressed by further research, which could also extend the policy relevance of the findings. Additional research should consider primarily how values change, and whether scope sensitivity becomes more apparent, when the scale of habitat loss is markedly increased. A contingent scenario based in the Severn estuary, for example, would allow comparison between barrages for which the potential mudflat loss ranges from less than 3,500ha to over 16,000ha (Hime and Ozdemiroglu, 2010), while plausible scenarios for more moderate habitat loss could be achieved using an estuary such as the Mersey, where the reduction in habitat has been predicted at between 500ha and 1,100ha, depending on operating mode (Wolf et al., 2009). Using scenarios in which the area of habitat loss changes by an order of magnitude would provide more robust indicators of the upper and lower bounds for which the elicited WTP is valid. Scenarios in which the area of mudflat lost is much larger would also allow the idea of a value hierarchy (in which local social concerns are considered more important than global environmental issues and local environmental impacts) to be tested for different scales of impact.

Distance decay effects should also be investigated further, in order to evaluate whether willingness to pay (WTP) remains constant or declines as the distance between the respondents' home and the affected site is increased to more than 100km. As well as the absolute distance, it would also be useful to consider how the type of location in which they live (rural, urban, coastal, inland) affects respondents' WTP.

Additional research could also determine whether WTP is generic, or varies according to the affected site. Factors such as whether the estuary is in an urban or rural area, and perception of the status of the estuary (e.g. whether it is already impacted or remains pristine) may influence WTP. This could be assessed empirically by determining WTP to reduce habitat loss in different UK estuaries such as the Mersey (urban, potentially perceived as impacted) and the Solway Firth (rural and likely to be viewed as much more pristine).

Obtaining more robust values from these suggested extensions to the research would further inform the economic case for (or against) barrage construction and mitigation measures.

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APPENDICES

I. An Assessment of the Environmental Benefits provided by the Taw Torridge Estuary

I.1 Information Sources

The Taw Torridge estuary is not well represented within peer-reviewed literature. A Web of Knowledge search for "Torridge" generated 17 references related to the estuary and "Taw estuary" just eight. There are several reports concerning the estuary and local area, which have been commissioned by interested parties. These include management plans for the estuary as a whole and for specific issues such as flood defence and catchment management, as well as reports on tourism, fisheries and the natural environment. Raw data are also available, which have been collected by conservation organisations and Government agencies, and include fish landings, water quality data, and species and habitat records. Personal communications have also been important sources of local information. The affiliations of the individuals referred to in the text are included in the references.

I.2 Identification of Stakeholders and Beneficiaries

Site Location

The Taw Torridge estuary is in North Devon (Figure 37). It is the confluence of the Taw estuary which runs east-west through Barnstaple to its tidal limit at SS 4750 2100 (near Bishops Tawton), and the Torridge, which runs north-south through Bideford to its tidal limit at SS 5695 2825 (near Weare Giffard). The estuaries converge near Instow and share a joint mouth, flowing out into Bideford Bay.

Figure 37. The location of the Taw Torridge Estuary

Defining the Local Area

An important group of stakeholders and beneficiaries are those people living in the closest proximity to the Taw Torridge estuary system. The selection of this 'immediate area' of the Taw Torridge (Figure 38) is somewhat arbitrary, but was chosen as the area within about 20km of the convergence of the rivers. This area includes the tidal limits of the estuary along both rivers, but not the full river catchment areas, which together cover more than 2000km^2 (Environment Agency, 2008). The limit of the region selected as the estuary's immediate area follows parish boundaries, as these are recognised areas for which data such as census information is available. The area is administered by the North Devon and Torridge Local Authorities, whose jurisdiction extends, respectively, to the east and to south and west of the delimited area (Devon County Council, 2007a,b).

The estuary cannot be isolated from the wider marine environment of Bideford Bay, and so the coastal and nearshore area of the bay, particularly between Baggy Point and Westward Ho!, also forms part of this assessment.

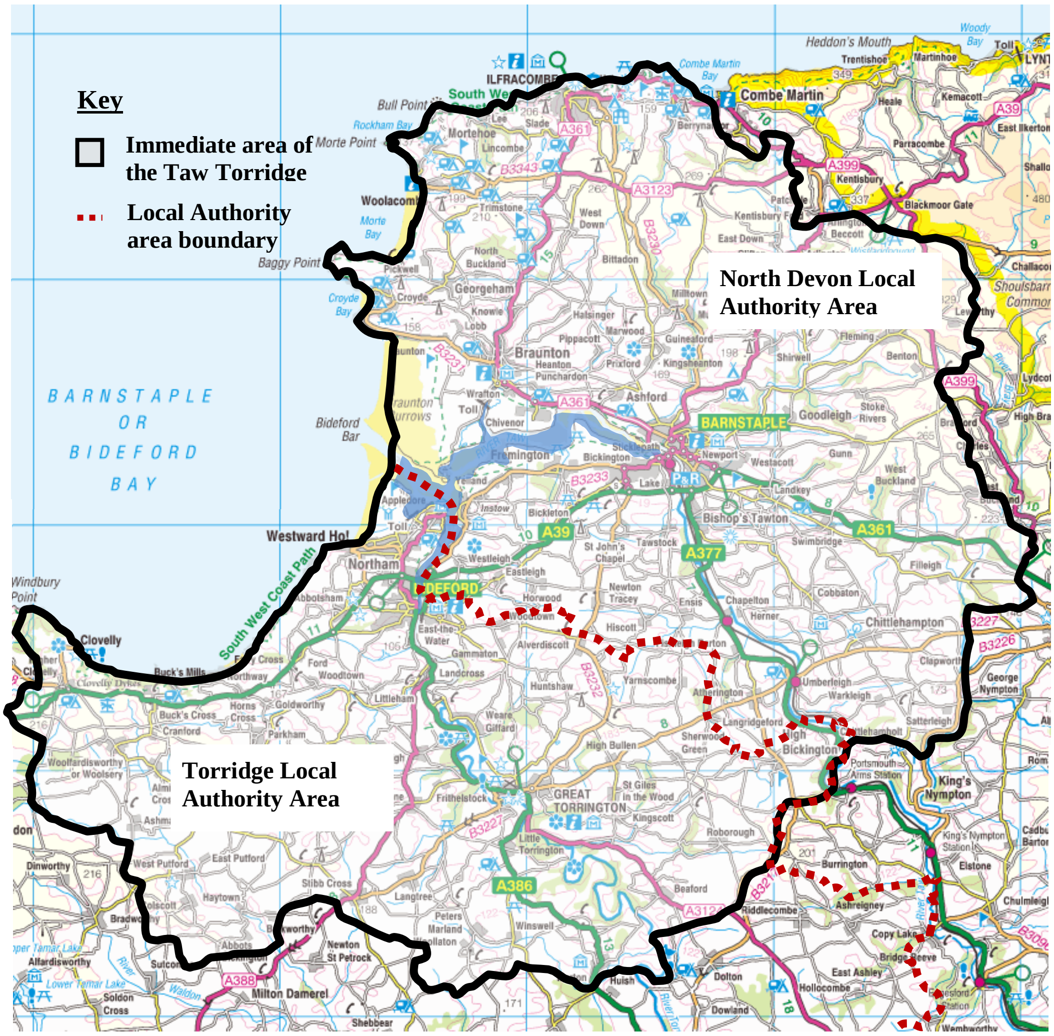

Figure 38. The region defined as the 'immediate area' of the Taw Torridge estuary and Bideford Bay coast

Protected Areas

There are four Sites of Special Scientific Interest (SSSI) within and adjacent to the estuary (Figure 39Figure 9). The entirety of the estuary was designated as an SSSI in 1988 under the Wildlife and Countryside Act (1981) (Natural England, 2001a). The principal reasons for designation were the populations of wading birds, the presence of rare shoreline plants and the mudflat, saltmarsh and sandbank habitats (Natural England, 2001a). Two smaller SSSIs are also found within the estuary: the Fremington Quay cliffs were designated in 1998 for their geological interest (Natural England, 2001b) and Northam Burrows was designated in 1988 for its coastal habitats, rare plants, bird populations and the Cobble Ridge landform (Natural England, 2001c). Braunton Burrows, to the North of the estuary on the Bideford Bay coast is also an SSSI, designated in 1986 primarily because it represents one of the largest dune systems in Britain (Natural England, 2001d).

The most recent report on the status of the SSSIs shows that Fremington Quay cliffs and the wider estuary are generally in a favourable condition, except for saltmarsh and mudflats in the Skern (near Appledore) which are in an unfavourable and declining condition due primarily to inappropriate coastal management (Natural England, 2010). The status of most of the SSSI sites at Northam and Braunton Burrows is also described as unfavourable, with the former site generally continuing to decline, while Braunton Burrows is mainly recovering (Natural England, 2010).

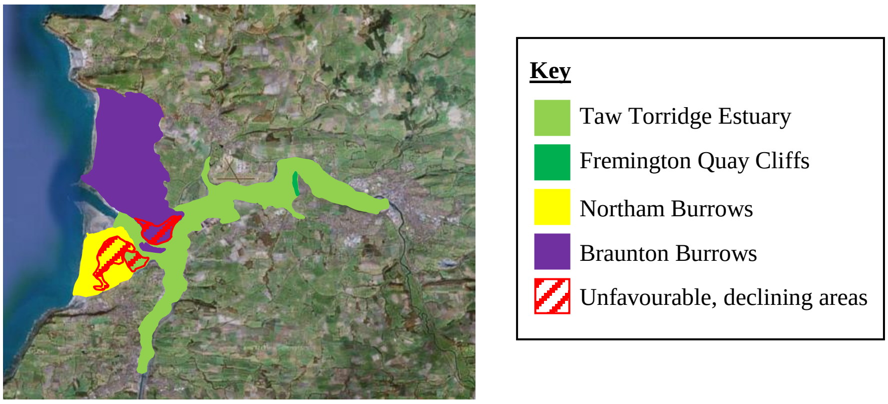

Figure 39. Sites of Special Scientific Interest within, and at the mouth of, the Taw Torridge estuary, highlighting those areas in an unfavourable and declining condition (from Natural England, 2010).

There is a small Local Nature Reserve protecting wet grassland adjacent to Fremington Pill (Natural England, undated), but otherwise additional protection of estuary sites predominantly relates to Braunton Burrows. Protection of the Burrows is significant as it is both a Special Area of Conservation under the Habitats Directive (JNCC, 2002) and forms the core zone of a UNESCO Biosphere Reserve (UNESCO, 2009). The whole estuary is included within the buffer zone of the Biosphere Reserve (North Devon Coast and Countryside Service, 2008). Braunton Burrows, and the coastline between Northam Burrows and Westward Ho! is also within the North Devon Area of Outstanding Natural Beauty (North Devon AONB Partnership, 2009).

Braunton Burrows has lost a degree of protection, however, as it was designated as a National Nature Reserve until 1996 (Davies, 1998). Also, the estuary was a candidate Special Protection Area under the Birds Directive until 1994, but this status was revoked following a sustained reduction in bird populations (Bell, 1996). Finally, while Braunton Great Field and Brauton Marsh are not currently protected, the opportunity for giving protected status to these areas under the Local Development Framework is being considered (Northern Devon Coast and Countryside Service 2010a).

Land Use

North Devon has low levels of urbanisation compared to the national average, but the highest levels of local urban development are found in the proximity of the Taw Torridge (Figure 40) (Environment Agency, 2008). Within the wider northern Devon region, of which the study area is broadly representative, grass and pasture is the predominant land use category (Figure 41) (Environment Agency, 2008), reflecting the widespread cattle and sheep farming in the area (DEFRA, 2007b).

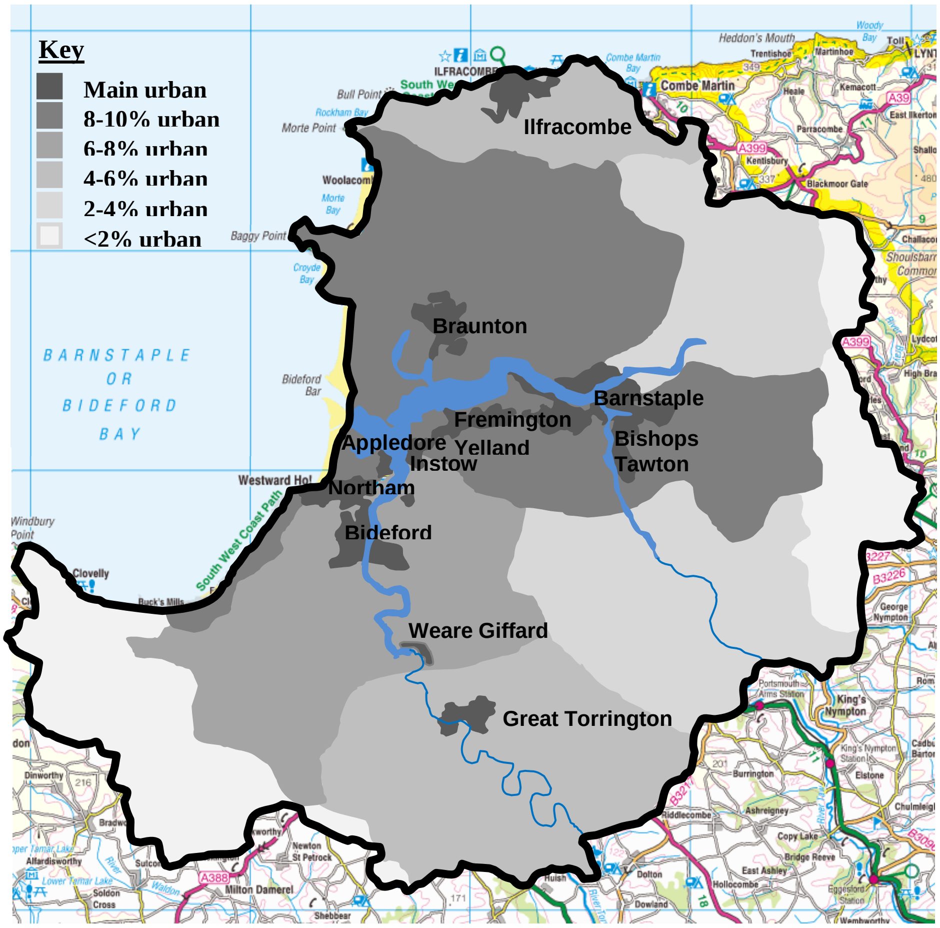

Figure 40. Levels of urbanisation within the area of the Taw Torridge Environment Agency, 2008)

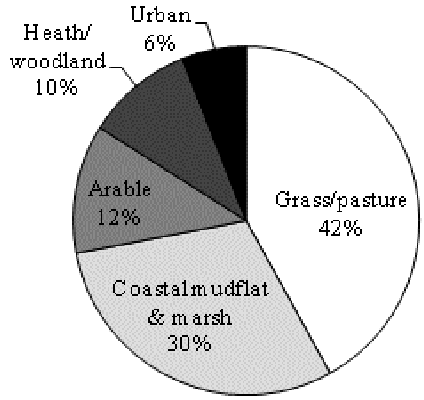

Figure 41. Land use categories within the North Devon river catchment area (from Environment Agency, 2008)

The Local Population

Size

Over 100,000 people live within the immediate area of the Taw Torridge estuary, which is about 75% of the total population of the North Devon and Torridge local authority areas (ONS, 2001). The main population centres on the estuary are the towns of Barnstaple, Bideford, and Braunton, with Great Torrington lying further upstream on the Torridge.

Ethnicity

In over 99% of households within the immediate area of the estuary, the household reference person (formerly the head of the household) is white, which is similar to the wider trend for this part of the county (ONS, 2001).

Age structure

The proportion of local people aged above 45years is considerable higher than the overall national trend (Table 42). The corresponding reduction in the number of younger people is most marked in the 25-44 age group. This would appear to suggest that older workers and those in retirement are attracted to the area, while people at an earlier stage of their career relocate elsewhere. Also, the percentage of younger people of working age (aged 16-44) is higher within the parishes immediately bordering the Taw Torridge than in the surrounding areas, suggesting perhaps that the comparatively large towns adjacent to the estuary attract people of this age group from the more rural areas of the wider region.

Table 42. The age structure of the population within the immediate area of the Taw Torridge compared to that in the wider North Devon and Torridge Local Authority (L.A.) areas, the South West region and England as a whole (derived from ONS, 2001).

	Parishes in the 'immediate area' of the estuary	North Devon L.A area	Torridge L.A. area	South West region	England
People aged 0-4	5.2	5.1	4.8	5.5	6.0
People aged 5-15	13.8	13.8	13.7	13.6	14.2
People aged 16-24	8.9	8.6	8.7	10.1	10.9
People aged 25-44	25.0	24.8	23.8	27.0	29.3
People aged 45-64	27.2	27.5	28.6	25.2	23.8
People aged 65-74	10.2	10.4	10.7	9.4	8.3
People aged 75 and over	9.7	9.8	9.7	9.2	7.5
Mean age of population	43.7	42.0	42.4	40.6	38.6
Median age of population	45.5	43.0	44.0	40.0	37.0

Economic Activity and Employment

This region of northern Devon is one of the more deprived parts of the county, and has more priority communities (those among the 25% most deprived nationally) than any other part of Devon (Northern Devon Partnership, 2009). Within the immediate area of the Taw Torridge estuary, Barnstaple, Bideford, Westward Ho!, Northam, and Appledore are all priority communities. Unemployment rates in both Barnstaple and Bideford exceed those of the immediately surrounding areas and are also higher than regional and national averages (Devon County Council 2006a,b). Wages in North Devon are 21% lower than the national average (Nankivell, 2010). The relative isolation and poor transport links affect the economic potential of the area, and isolation is also a contributing factor to the high proportion of small businesses in the area, compared to regional and national trends (Northern Devon Partnership, 2009).

The rural, coastal nature of the location results in the increased importance of agriculture, tourism and fishing in terms of the proportion of the workforce employed within these sectors, when compared to the wider regional and national averages (ONS, 2001). In absolute terms, fishing remains a small sector: in 2001 the actual number of people employed in fishing across the whole of the North Devon and Torridge Local Authority areas was only 84 (ONS, 2001). Of much greater importance were the three sectors of wholesale, retail and motor repairs; manufacturing; and health and social work, which together employed 45% of the workforce (ONS, 2001). Hotels and catering was fourth largest sector, employing 10% of workers. A similar trend is found when the gross value added (GVA) of the different industrial sectors is considered (Figure 42).

Tourism is more important to the area than these figures initially suggest: hotels and catering are the core of the industry, but tourism-related activities cross many other sectors. It has been estimated that tourism supports over 20,000 jobs (Northern Devon Partnership, 2009), and was worth £375million to the economy in 2008 (Nankivell, 2010). During the holiday season, tourism causes a threefold increase in population (Northern Devon Partnership, 2009), indicating the importance of tourists as beneficiaries of ecosystem services.

The relative importance of the estuary and coastal area to tourism is difficult to assess. Coastal destinations in North Devon and Torridge have consistently represented about 20% of day trips to those areas since 2001, even after 2003, when urban destinations became more important at the expense of countryside locations (South West Tourism, 2003-2010). Day visitors contribute only about one third of the annual tourism spend in the area (South West Tourism, 2010), but information on the relative importance of coastal locations to staying visitors does not appear to be easily available. The number of tourist nights has been stagnant since 2002 and tourism in North Devon is growing less strongly than in other parts of the county, perhaps due to the lack of cities, which are the main areas of growth in Devon tourism (Nankivell, 2010).

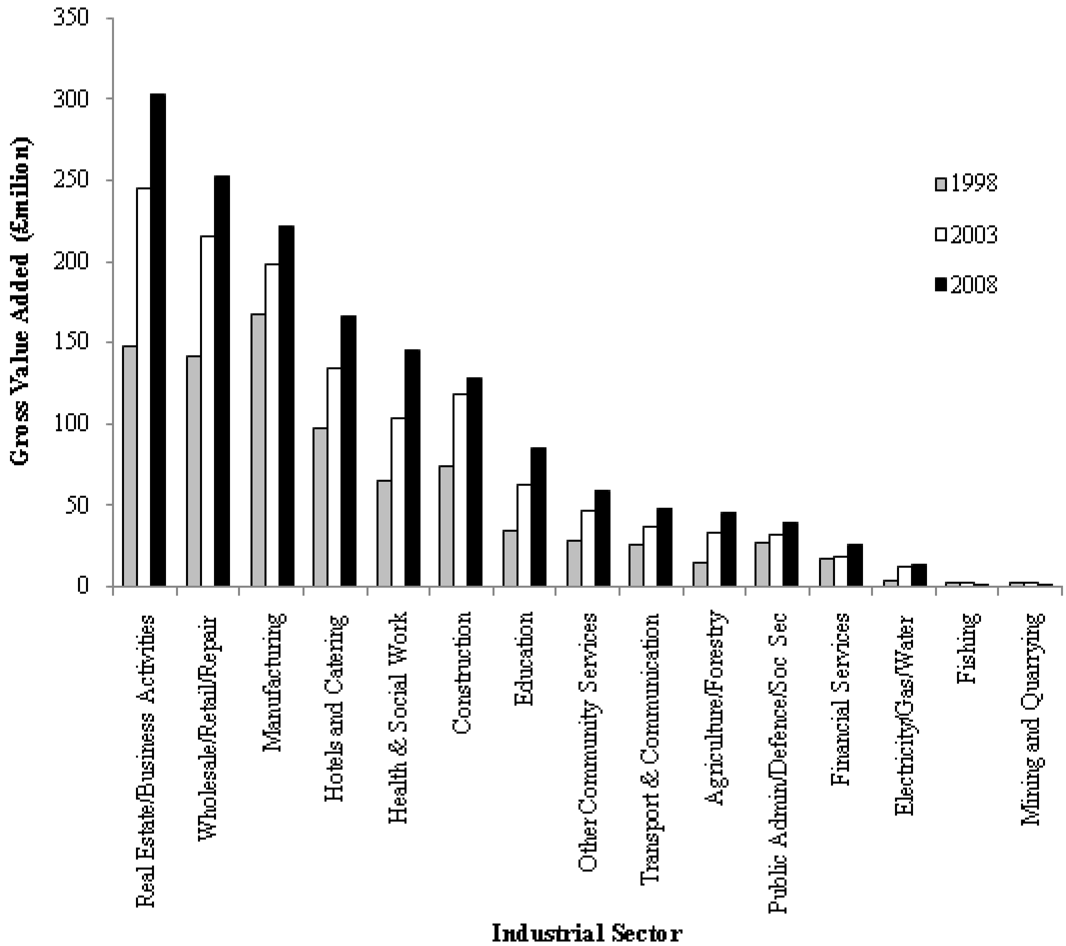

Figure 42. The gross value added contributed to the economy of North Devon and Torridge by different industrial sectors

Within manufacturing, there are marine-related small businesses in the area (such as J&S Marine, which makes marine components in Pottington) but their operations have no direct connection to the estuary (Ellen Vernon, pers. comm.). The only significant manufacturing industry with any actual reliance on the estuary is the Appledore shipyard, owned by Babcock International's Marine division. The yard employed just under 300 people in 2010 (Nigel Babb, *pers. comm*.).

A survey in 1998 suggested that 68% of the local workforce were employed by companies with some direct or indirect link to the estuary (TTEP, 1998). The estuary was important to the companies as a venue for tourism, for the landscape and wildlife, and for land and water-based recreation.

There is considerable local interest in the renewable energy sector as a potential area of growth and job creation (Northern Devon Partnership, 2009). One possible focus for this is at Yelland, the 70 hectare brownfield site of the former powerstation, which is currently competing to become the operations and maintenance port for the Atlantic Array, a large offshore windfarm development to be located off the north Devon coast (Peter Qunicey, *pers. comm*).

I.3 Production Services

Food

Shellfish

There are eight designated bivalve production areas in the Taw Torridge estuary, seven for mussels (*Mytilus edulis*) and one, at Zeta Berth, for mussels and Pacific oysters (*Crassostrea gigas*) (Food Standard Agency, 2010) (Figure 43). The oyster fishery is currently inactive, although previously up to 20,000 oysters were farmed at Zeta Berth (John Daniel, pers. comm.). There is no designated production area for cockles (*Cerastoderma edule*), although these have been harvested in the past from Instow sands (Paul Carter, pers. comm.). Common periwinkles (*Littorina littorea*) have previously been collected at Appledore and Crow Point (TTEP, 1998), with landings exceeding two tons during a winter season (John Daniel, pers. comm.). A recent attempt to revive the winkle fishery is not proving successful (Paul Carter, pers. comm.).

Mussel harvesting takes place by hand: an operation to dredge for subtidal mussels was piloted but not repeated (Paul Carter, pers. comm.). Controls on the mussel fishery take the form of a minimum size limit of 2", which the Environment Agency is responsible for enforcing, and the District Councils monitor the hygiene of the beds. The quantity of mussels removed from the estuary is not routinely recorded.

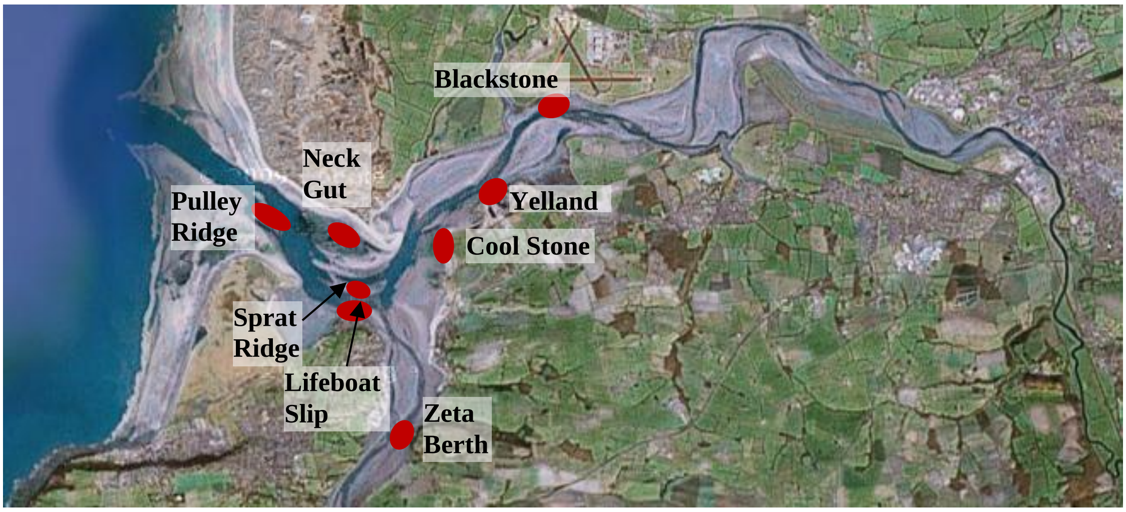

Figure 43. The main shellfish harvesting areas in the Taw Torridge estuary

The Taw Torridge has one of the largest natural mussel stocks in the south west (TTEP, 1998). A 2001 assessment (Walker, 2001) suggested that the combined stock size at Pulley Ridge, Sprat Ridge, Cool Stone and Yelland exceeded 2,000 tonnes, of which about 300 tonnes exceeded the minimum size limit and was therefore exploitable. The largest individual bed was at Pulley Ridge, but only about 40 tonnes (less than 1% of the stock) was of exploitable size (Walker, 2001) due to wave and current action regularly scouring the bed, which is on a sand and cobble substrate (Paul Carter, pers. comm.). Sprat Ridge also has a low proportion of larger mussels, for the same reason. The largest exploitable resource (210 tonnes) was at Cool Stone, and Yelland also had a high proportion of large mussels, but these mussels are less commercially desirable due to barnacle settlement (Walker, 2001).

About six mussel fishers work in the estuary. Discussions with local harvesters suggest they work for about three to five days per fortnight on the low spring tides and can harvest in the region of 0.5-1.0 tonne per spring tide. Harvesting is lower over the summer months as the mussels are of lower quality due to spawning activity and the fishers may be engaged in other economic activity during this period. An average harvesting season can yield about 30 tonnes of mussels, although a reported record seasonal harvest was nearly 90 tonnes.

The mussel fishery is seriously affected by water quality issues, and was completely closed for several years from 1992 (TTEP, 1998), reopening again following a significant upgrading of the sewage treatment system. Currently, most of the beds are designated long term Class B (Food Standards Agency, 2010), allowing the harvested mussels to be sold for human consumption following appropriate depuration to neutralise any harmful bacteria (usually achieved through UV treatment). However, the Cool Stone and Pulley Ridge beds are Class C, which requires the mussels to be relayed at an approved site (Fowey in Cornwall) for at least two months prior to depuration (Food Standards Agency, 2010).

Mussel bed testing focuses on the levels of the *E. coli* bacteria detected in the animals' flesh, and how these compare to recognised safety standards. Unusually high *E. coli* levels may be detected during routine monitoring (Figure 44) and these may cause other mussel beds within the estuary to be temporarily downgraded to Class C pending an investigation. Such temporary downgrades have occurred after unusually high rainfall events or failures within the sewage system, and can remain in force for many months (Dean Davies, pers. comm.).

Depuration facilities have been set up locally, but these have not been maintained due to the repeated downgrading of major beds, and so mussels from Class B beds are sent to Exmouth for treatment. Exploitation of mussels from Class C beds does take place, but is not considered economically viable.

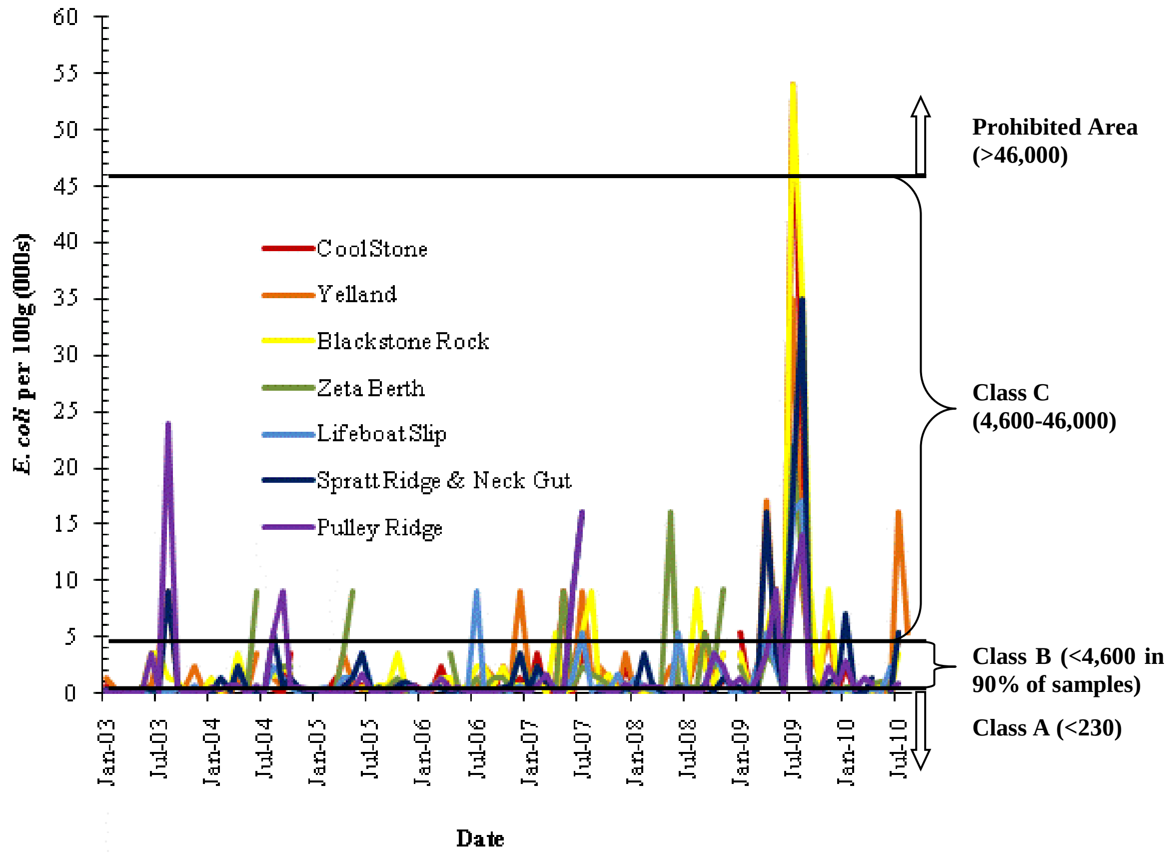

Figure 44. The number of *E. coli* per 100g of mussel flesh detected during routine sampling of mussel beds in the Taw Torridge estuary since 2003 (UK National Reference Laboratory, unpublished data) and the threshold levels for Shellfish Production Area classifications (Food Standards Agency, 2010).

Salmonids

The population of salmon in the Torridge is considered to be probably at risk, while that in the Taw is probably not at risk (Environment Agency, 2010d). Both the Taw and Torridge have Salmon Action Plans in place, and the Taw is designated as a Special Area of Conservation, in which salmon must be maintained or restored to favourable conservation status (CEFAS & Environment Agency, 2010).

Management measures have been put in place to reduce fishing effort, but the stock is also suffering from low levels of recruitment, due to poor water quality in spawning and nursery grounds, which have been affected by siltation (Northern Devon Coast and Countryside Service 2010a).

Netting for salmon and sea trout continues in the Taw Torridge, but is being phased out. A buy-out of net licences in 2002 saw numbers drop from 14 to 3, and these remaining licences will not be replaced once existing netsmen leave the fishery (CEFAS & Environment Agency, 2010). Netting is permitted between 1 June and 31 August (Environment Agency, 2009a), but additional byelaws further reduce the period during which fishing is permitted, and average net fishing effort was just 20 fishing days per licence in 2009 (CEFAS & Environment Agency, 2010). Licence holders are required by law to supply catch data, which is published by the Environment Agency (2009a). In 2008, 61kg of salmon (17 fish) and 63kg of sea trout (100 fish) were landed (Figure 45).

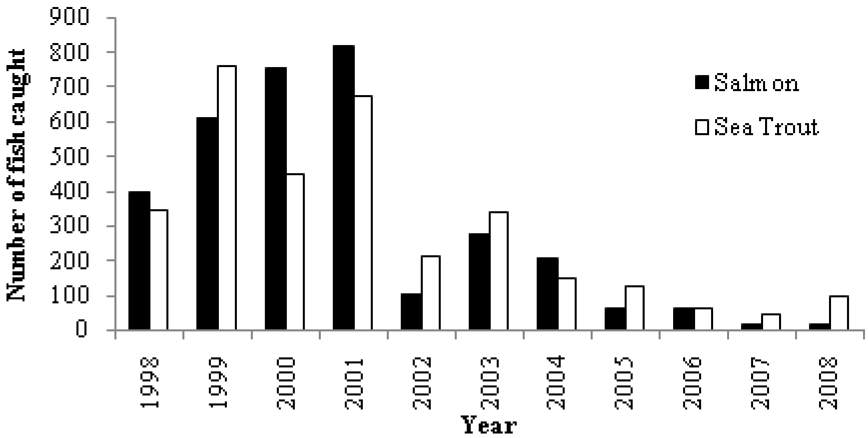

Figure 45. Total annual landings of salmon and sea trout from the Taw and Torridge reported by net licence holders between 1998 and 2008 (data from the Environment Agency, 2009a)

Eels

There is a lack of available data on the population of eels (*Anguilla Anguilla*), found in the estuary. There is some evidence to suggest that recruitment may have declined since the late 1970s, although the impacts on upstream populations in the Taw may have been minimised as a result of the location of the estuary (facing the elver Atlantic migration pathway), and the role of salt marsh areas as recruitment reservoirs (Knights et al., 2001). The Taw Torridge elver fishery has been the third most important in the region after the Severn and Parrett, and about 130-200kg of elver landings were declared annually between 2005 and 2007 (DEFRA, 2010b). This may not represent the total landings, as elver poaching has historically been a problem in the estuary (TTEP, 1998). Fishing effort is difficult to quantify, as elver dip net licences cover the Devon and Wessex region, and the licence holder can fish any river within that area. About 25 people probably fish the Taw Torridge, of whom about half are local and the remainder are fishers from the Bridgewater and Gloucester areas who fish the Taw in addition to their own local rivers (Paul Carter, pers. comm.). In 2010 there were no fyke net licences for catching adult eels on the Taw Torridge (Paul Carter, pers. comm.)

Fishers have been obliged to declare their catches since 2005, and are also subject to a number of fishing restrictions, including a recent prohibition of all elver fishing until February 2011 (Environment Agency, 2010f). The Environment Agency is currently seeking to implement further byelaws, which would restrict eel netting to just the estuary area and would impose closed seasons from 1 October to 25 June for eels and 11 May to 14 February for elver (Environment Agency, 2010g).

Marine Fish

Seasonal seine net sampling by the Environment Agency (unpublished data) shows that the estuary is used by eleven marine fish species that are important for food. There are too few data to make any detailed or definitive assessment of species abundance and behaviour within the estuary. However, the information does suggest that the estuary is particularly important for bass (*Dicentrarchus labrax*), two species of mullet (*Chelon labrosus* and *Liza ramada*), flounder (*Platichthys flesus*), and plaice (*Pleuronectes platessa*). These species use the entire estuary area, having all been found at sampling sites close to the tidal limits in both rivers (Figure 46). Golden grey mullet (*Liza aurata*) and herring (*Clupea harengus*), are also relatively abundant at certain sites within the estuary.

The Environment Agency data (Figure 46) appears to show some seasonal variation in use of the estuary by the different species, particularly upstream in the Taw at Barnstaple where flounder and plaice dominate the samples collected in May/June but mullet are more abundant in October. Samples from the other sites taken in October are dominated by bass, with other species becoming more abundant in May/June.

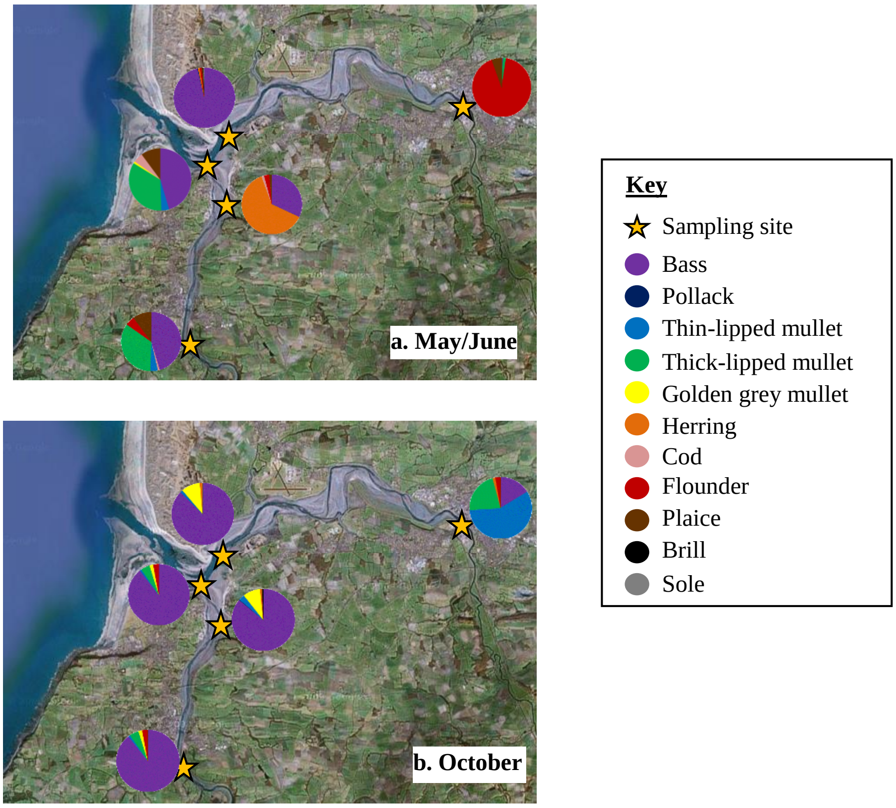

Figure 46. An indication of the relative abundance of important species of edible marine fish at different locations within the Taw Torridge estuary during (a) May/June and (b) October, based on a small dataset (Environment Agency, unpublished data).

Historically, more detailed research has been carried out on bass populations. The Taw Torridge is a nursery area for bass: it is used mostly by juvenile fish of less than one year old, which begin arriving in July and overwinter in the estuary (Kelley, 1986). The deeper channels may be particularly important to overwintering bass, especially the Braunton Pill area, although its favourability may be reducing due to siltation, which that has been occurring since at least the 1990s (Kelley, 1986; 2002). Bass also use the shallow upstream areas for their first two summer growth periods (Kelley, 2002). To protect juvenile bass, a bass nursery area was established in 1990, within which bass netting is prohibited between 1 May and 31 October (MAFF, 1990) (Figure 47). Trawling and set netting are also prohibited within the estuary, and there are statutory controls on mesh sizes and on minimum landing sizes for different species.

A small number of small-scale commercial fishers do drift net for bass and mullet within the estuary. Catch sizes are not routinely monitored, but anecdotal evidence suggests that fewer mullet use the estuary, and that this decline was coincident with sewage clean-up operations (John Daniel pers. comm.). This size of individual fish landed is also decreasing.

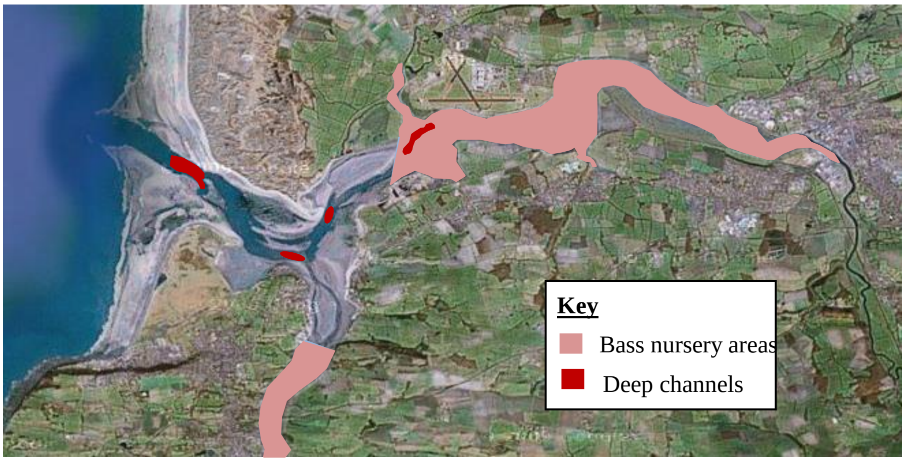

Figure 47. Bass nursery areas within which seasonal fishing prohibitions are enforced, and additional deep channels which may be of particular importance to overwintering juvenile bass.

Inshore Fisheries

Commercial fishing effort within the estuary itself is low, but substantial fishing effort does occur beyond the Bideford Bar. Given the number of commercial marine fish species using the estuary, it is relevant to include the inshore fishery within this assessment. The fisheries operating beyond the mouth of the estuary were considered using unpublished data supplied by the Marine Management Organisation (MMO). Fishers operate out of Appledore and Bideford – Barnstaple is no longer an active fishing port. As at 01 August 2010, there were 26 licensed fishing boats operating from ports within the Taw Torridge estuary: 14 in Bideford, 8 in Appledore and 4 in Barnstaple (MMO, 2010b). Of these only four were more than 10m in length. The fishers mainly use gillnets, otter trawls and pots, and most vessels deploy multiple gear types.

Catches are landed at both Appledore and Bideford, by vessels based outside the area as well as by the local boats. Until 1997, Bideford was the most important port in terms of the total value of catch landed, but in nine of the twelve years between 1998 and 2009, landings at Appledore have accounted for more than 90% of the total value of fish landed at the estuary ports each year. The increased landings at Appledore reflect the expansion of the fish dock at Bidna Quay, which has housed a fish processing business since 1999 (Garrett and Myers, 2005). The quay has also benefited from a £3.6million renovation, which was completed in 2009. This was undertaken to prevent structural failure of the quay and to further improve facilities and operations (Garrett and Myers, 2005). There are no processing facilities at Bideford (the catch is taken to Appledore), and finfish landed at Ilfracombe are also processed at Appledore (John Butterworth, *pers comm*).

Between 1990 and 2009, total landings at the estuary ports varied considerably year on year, and ranged in value from £400,000 (in 1990) to £1.5million (in 2001). These landings are small when compared with those from other ports in the south west such as Brixham, Newlyn and Plymouth, where mean annual landings exceeded £10million for each port during the five year period from 2005 to 2009. However, most of the larger fishing ports are in the south. Landings at Appledore represented 14% of the value of catches landed along the north coast of Devon and Cornwall, making it the fourth largest port serving this area.

Landings of 69 different species or groups have been recorded at the estuary ports, of which demersal fish are the most valuable, representing at least 74% of the total catch value each year between 1990 and 2005. Since 2006, mollusc and crustacean species have become relatively more important, in terms of their proportion of the total catch value. Historically, scallops have not been an important component of the shellfish catch, although a local fisher is expected to begin scallop dredging in 2011 (John Butterworth, pers. comm.) Pelagic fish species make only a very minor contribution (<1%) to the total value of the fishery (Figure 48).

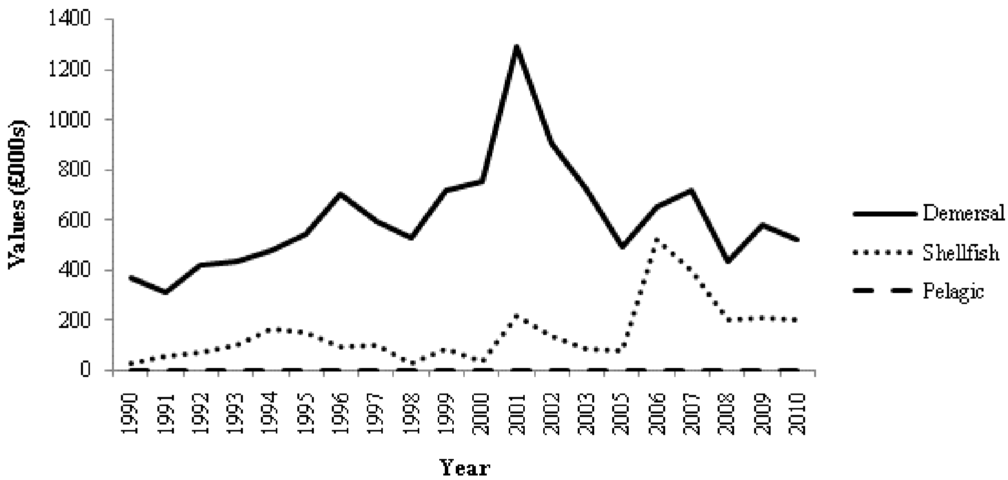

Figure 48. The value of the different components of the combined catch landed at Appledore and Bideford between 1990 and 2009 (from MMO, unpublished data).

Not all landings are recorded by individual species, as this is not always required and identification to species level may not always be possible. The different species were therefore grouped by family to allow comparison of the relative importance of different groups. Eight families represent 90% of the value of the total catch landed between 2004 and 2009 (Figure 49). 75% of the total catch value resulted from landings of skates and rays (Rajidae), squid (*Loligo spp.*), bass, (*Dicentrarchus labrax*) and whelks (*Buccinum undatum*). Lobsters (*Homarus gammarus*) are also important, as are flatfish, particularly sole (*Solea solea*) and turbot (*Scophthalmus maximus*). While the generic code for fishery data collection is ‘skates and rays’, rays comprise the vast majority of the catch. Rays have been recorded as individual species since 2008, although the system is in transition and use of the generic code still permitted. Species of ray caught are the small-eyed ray (*Raja microcellata*), thornback (*R. clavata*), blonde ray (*R. brachyuran*), spotted ray (*R. montagui*), sandy ray (*Leucoraja circularis*), and cuckoo ray (*Raja naevus*).

Fish landings data also includes records of the fishery rectangle in which the animal were caught. The total landings at Appledore and Bideford include fish caught within the coastal waters of a wide area of the southwestern UK, extending from Swansea in south Wales to Swanage in Dorset (Figure 50). However, 95% of the catch value came from animals taken within the rectangle closest to the landing ports (31E5), which includes the area likely to be influenced by the Taw Torridge.

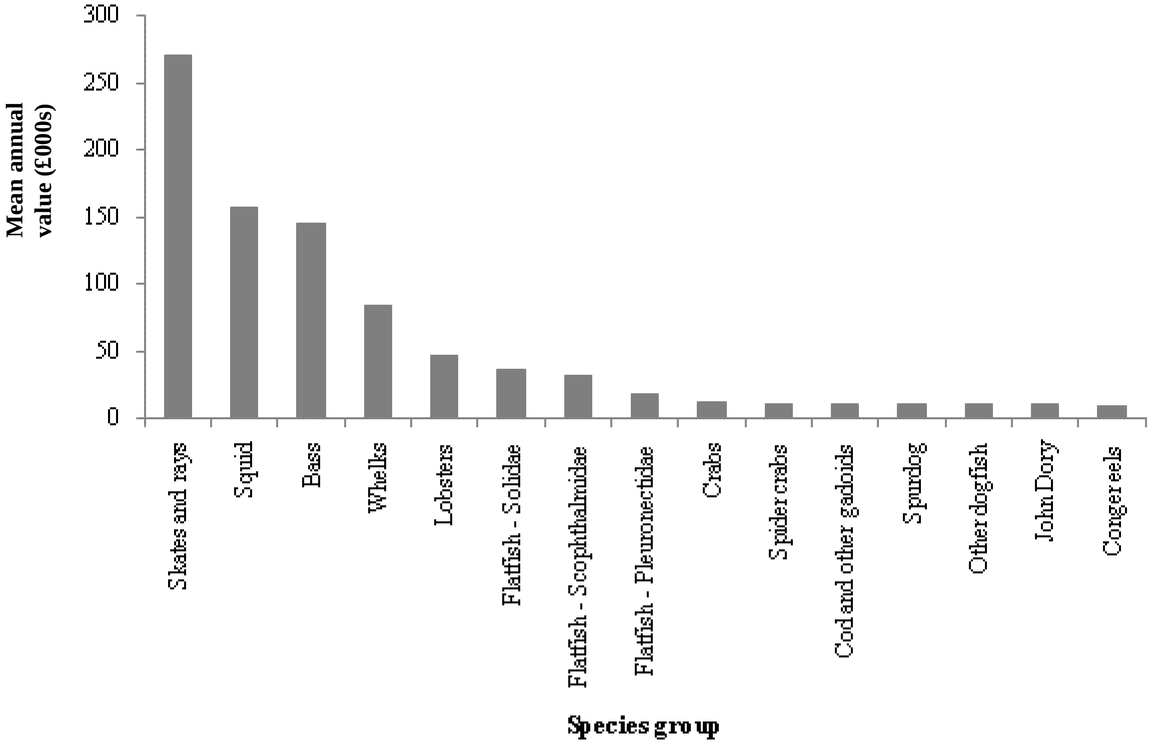

Figure 49. The relative importance of different species groups within the total catch landed at Appledore and Bideford between 2005 and 2009 (unpublished data from the MMO)

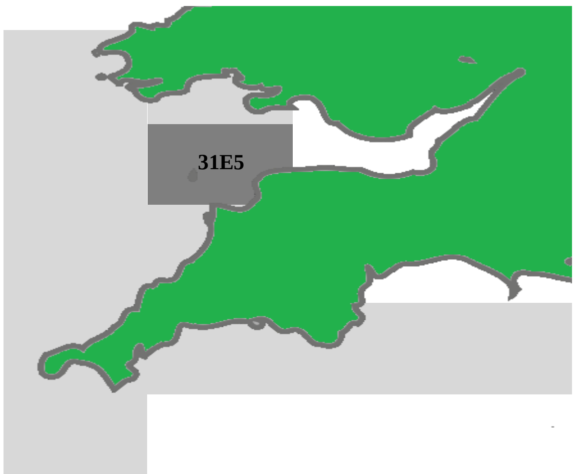

Figure 50. ICES rectangles from which commercial fishery species landed at Appledore and Bideford are caught, highlighting the location of rectangle 31E5 (MMO, unpublished data)

Not all of the ships fishing in this area closest to the Taw Torridge have a local home port. Other ships, registered in other parts of England, Wales, Belgium, Guernsey and the Isle of Man also fished the area regularly in recent years. The catches from these ships were landed at 34 different locations, which were mostly around the coasts of Devon, South Wales, Cornwall, and Somerset but also included ports in North Wales, Liverpool and, occasionally, as far afield as the Firth of Clyde. The boats deploy a range of gear types, including beam, otter and pair trawls, pots, gillnets, various lines and mechanized dredges.

During period 2005-2009, species groups making up the most significant portion of the catch were similar to the landings at Appledore and Bideford, although distribution of value amongst the species was more even. More than £2.5million of fish and shellfish was caught in rectangle 31E5 on average each year, and 25%-37% of this annual catch (by value) was landed in the estuary ports. Other ports with mean annual landings from 31E5 valued in excess of £100,000 are Ilfracombe (over £0.9m), Milford Haven, Swansea, Padstow and Neyland.

There appears to be a lack of studies that assess the catches of inshore fisheries, or the distribution of target stocks, at a resolution finer than the fishery rectangle. Attempts have been made, for example in relation to the Atlantic Array offshore wind farm development, but the mobile nature of most fishing techniques makes the precise location of catches difficult to determine (John Butterworth, pers. comm.). A study has examined the lobster fishery, which shows that local boats do set their pots within a coastal strip that extends southwards from Northam Burrows and also around Croyde Bay and Baggy Point (Clark, 2008), although data was not provided to allow determination of the importance of the catch from these areas. Lobster fishery effort appears to be greater in areas further from the estuary, particularly around Lundy Island and off the northern coast from Morte Point to Foreland Point.

Were marine renewable energy developments to have any impact on the fisheries of the area, the implications could potentially be widespread. The likely effect of a barrage on the local inshore fisheries proved impossible to determine, as there do not appear to be any studies of existing tidal or impoundment barrages that consider this issue. Fisheries have, however, continued out of, for example, St Malo and Cardiff, following construction of the La Rance and Cardiff Bay .

Exported spat/broodstock, marine plants and grazing

During 2000, 40 tonnes of seed mussel was taken from Pulley Ridge to lays in the Wash (Walker, 2001), but no significant export of this type has occurred since. Small scale collection of purple laver (*Porphyra* spp) for local consumption occurs between April and September from a site at the estuary mouth, and the algae is used by local restaurants and sold at Barnstaple market (TTEP, 1998; Andy Bell pers. comm.). Limited use has been made of saltmarsh areas near Fremington for grazing lamb (Andy Bell, pers. comm.)

Raw Materials

Bait

Most bait is collected for personal use. The closure of local tackle shops has reduced market opportunities, and only one commercial bait harvester operates in the estuary (Andy Bell, pers. comm.). Fishermen dig mainly for the harbour ragworm (*Hediste diversicolor*), as well as other ragworm and lugworm (*Arenicola marina*) (Tony Gussain, pers. comm.). Bait digging is common over a considerable distance around Bideford and Barnstaple, and in mud flats in other parts of the estuary (Tony Gussain, pers. comm.; WS Atkins, 1993; TTEP, 1998) (Figure 51). Most of these sites are near to bird feeding and roosting areas (WS Atkins, 1993).

Peeler crabs (moulting *Carcinus maenas*) are also collected for bait. Effort is concentrated during the spring and autumn, and involves laying tiles or guttering pipes on the shore, under which crabs take refuge and are then easily collected (Tony Gussain, pers. comm.). Crab tiling is on the increase (John Daniel pers. comm.), and concern that it would become unsustainable led to the development of a voluntary code of conduct, to which most collectors adhere (Northern Devon Coast and Countryside Service, 2010a.)

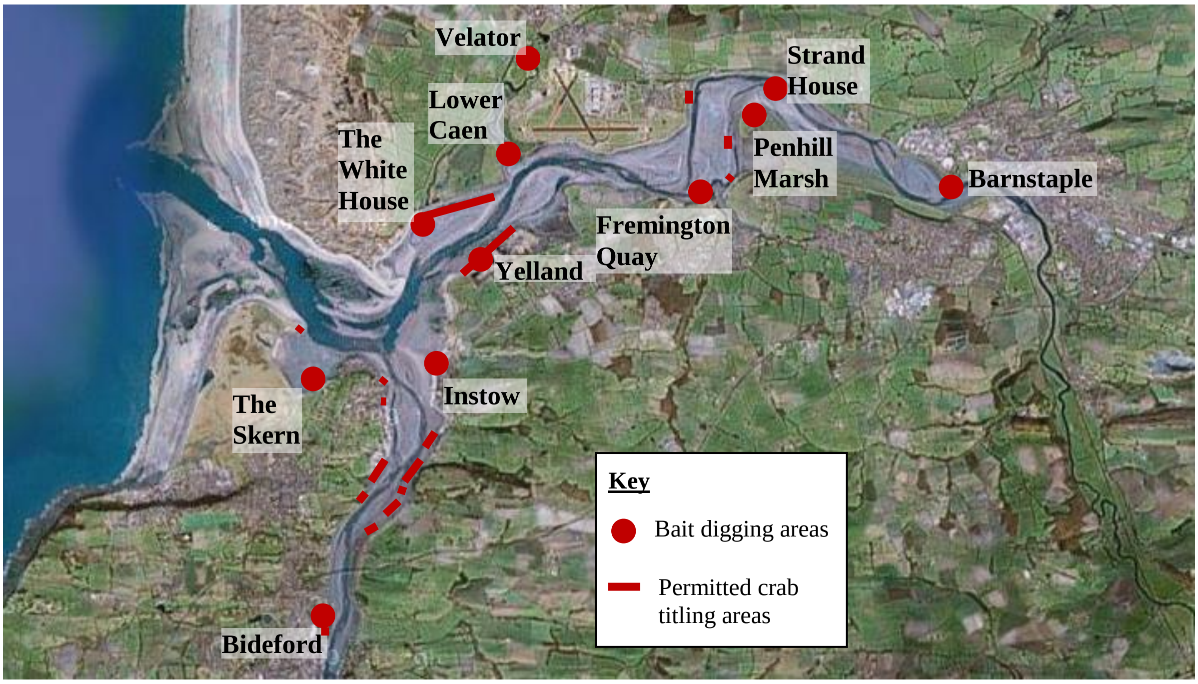

Figure 51. The main sites within the estuary used for collecting bait, including those to which crab tiling is restricted under the voluntary code of conduct

Aggregates

Between 1982 and 1998, up to 45,000 tons of aggregates were extracted annually from four sites within the estuary, although this was limited in the latter years to extraction of about 15,000 tons per year from the Crow Point area (NRA, 1993; TTEP, 1998). Commercial extraction has since ceased, due primarily to concerns about the erosion of Crow Point. More recently, small-scale operations occur occasionally to extract sand for use on, for example, farmland (Bideford Harbour Master, pers. comm.). There is also no aggregate extraction from the wider Bideford Bay area (Crown Estate, 2009).

I.4 Carrier Services

Provision of Space

Commercial Transport

There is no commercial shipping using the Taw: siltation has affected navigation to Barnstaple and the two prominent jetties within the Taw estuary (the oil terminal jetty at Instow, and powerstation jetty at Yelland) are no longer operational. Should Yelland be selected as the operations and maintenance port for the Atlantic Array, then shipping would once again regularly use this site. Within the Torridge, Bideford provides 300m of quay front and regularly handles ships over 90m long with draughts of 4.5m (Torridge District Council, 2010). The larger of these ships are restricted to spring tides, as only ships with a draught off less than 2m can be accommodated on a daily basis. Commercial shipping also frequently uses the quay at Appledore (Figure 52).

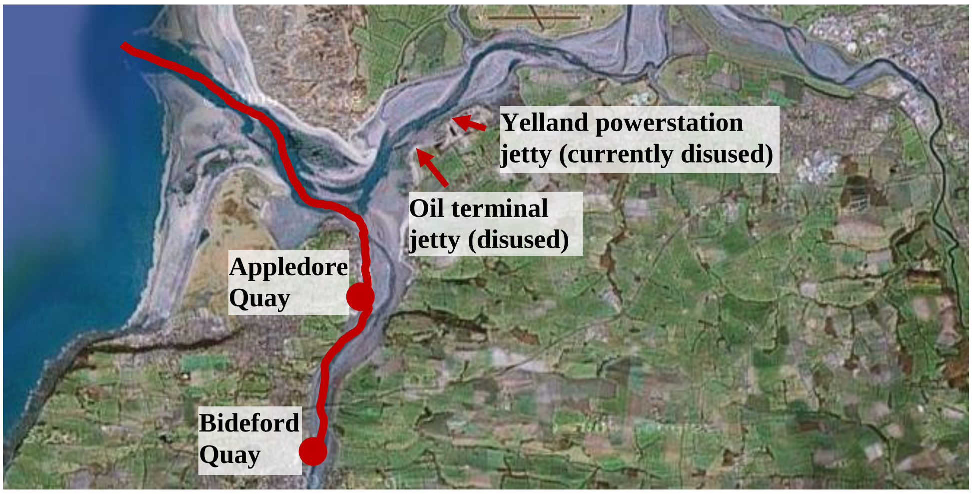

Figure 52. The location of the quays at Bideford and Appledore, and the main route for commercial shipping

During the period April 2009 to April 2010, six ships arrived into Bideford, most of which were exporting ball clay (2-3,000tons per load) from local quarries, while one brought in a 1,500ton load of road salt (Bideford Harbour Master, unpublished data). During this period, more commercial shipping used the quay at Appledore, where an average of 3 ships arrive per month (range 0-7) mostly importing aggregates but also transporting other items, for example ship sections for the local shipyard. Shipping for surveys or other special projects (such as removing the piles from the Marine Current Turbines prototype device at Lynton) are also handled at Bideford (Torridge District Council, 2010), as is the *MV Oldenburg* ferry, which carries up to 267 passengers and operates about five return services per month to Lundy between April and October (Lundy Island, 2010).

Much of this shipping activity is related to the building industry, and there has been a decline in this traffic as a result of the economic downturn (Northern Devon Coast and Countryside Service, 2010a). Conversely, shipping servicing the Appledore shipyard has increased following the recent award of contracts related to aircraft carrier construction, and new opportunities for Bideford are being explored such as the potential development of the port facilities for shipping of waste glass to Ellesmere Port for recycling (TTEF, 2010).

The estuarine sediment is very mobile, so navigable channels move over time and ships' berths may require dredging. The main shipping channel itself, however, is scoured to a sufficient depth by fluvial and tidal flows and no dredging is necessary to maintain it (Bideford Harbour Master, pers. comm.).

Mooring

Commercial inshore fishing boats moors at Appledore and Bideford, and recreational boat mooring occur in large numbers off Applefore and Instow, with some also located in the Caen towards Braunton. These moorings are largely unregulated, a situation that appears to have arisen because Appledore's free port status has been interpreted to mean that mooring buoys can be sited anywhere and also because the foreshore has multiple owners, who have shown little interest in managing the mooring sites (Tony Pratt, pers. comm.). The Taw Torridge is also used to moor residential houseboats. This is controlled within the Bideford harbour area (where three boats moor), but unregulated in the Taw, where houseboats moor at Heanton, Wrafton and Velator (Tony Pratt, pers. comm.).

Military Operations

Military use of the Taw Torridge is focused on Chivenor, Braunton Burrows and Saunton Sands, Instow and particular shores within the estuary (Figure 53). The Chivenor base is home to the Royal Marines Commando Logistics Unit, 24 Commando Engineer Regiment and also A Flight 22 Squadron, Royal Air Force, who mainly conduct helicopter Search and Rescue duties (MOD, 2010). Braunton Burrows has been used for a range of military training activities including driver training and simulated warfare exercises to provide exposure to the difficulties of operating in sandy conditions (Loch, 2007). The Burrows is used as a firing range, which currently involves only blank rounds, although live ammunition undoubtedly remains in the area (Sgt Andy Middelton, pers. comm.). The frequency with which the Burrows is used may reduce following the closure of the military base at Fremington in December 2009, and the associated loss of overnight accommodation. The beach at Saunton, adjacent to Braunton Burrows, is also used by the Army, Navy and Air Force for exercises involving amphibious vessels and aircraft landings (Loch, 2007).

The focus of amphibious vessel use in the estuary is the Royal Marines 11 (Amphibious Trials and Training) Squadron (the ATTU), which is based at Instow. Amphibious craft training has occurred here since 1942: the area was chosen as it more closely resembled the conditions on the Normandy coast than anywhere else in the UK, and it also provided a wide range of beach types, gradients and levels of exposure (Ferguson, 1961). The beach at Instow is flat (with a gradient of 1:120) and sheltered, allowing its use in all weather, while that at Saunton has a similar gradient but heavier surf conditions. Crow Point provides a steep incline, the Greysands area is a pebble beach, and riverine mud flats are found upstream of Yelland in the Taw.

Instow beach is the most heavily used site, and is the focus of the vehicle driver training courses, which occur very frequently throughout the year (Sgt Andy Middelton, pers. comm.). Landing Craft are used during the driver training exercises, to provide practice in loading and unloading the vehicles, and transport between training sites. Training in the operation of the Landing Craft themselves is also carried out from Instow, with about four courses run each year. The base also provides additional vessel training courses for outside agencies including the police and Hydrographic Office (Sgt Andy Middelton, pers. comm.).

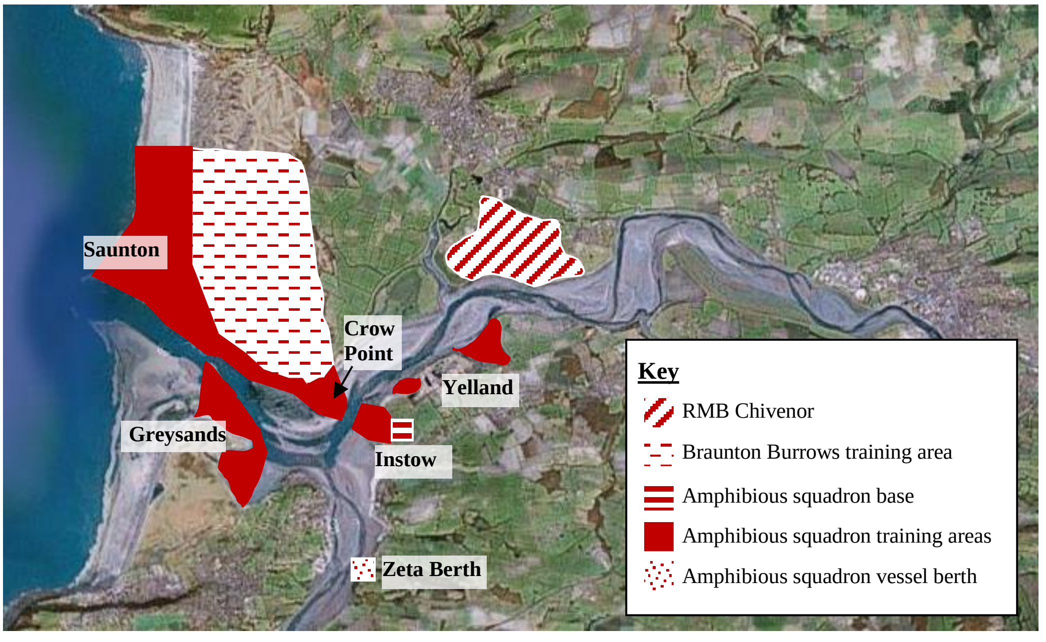

Figure 53. The areas of the estuary used by the military

Cables and Pipelines

At least one sewage pipeline crosses the bed of the Torridge, taking effluent from Instow and Yelland to the treatment works at Cornborough (South West Water, 2002). An underwater route is rarely preferred for telecoms cables, because the use of specialist contractors, equipment and procedures as well as the ongoing maintenance requirements are unlikely to make such a route the most cost-effective option (Robert Owen, pers. comm.). No telecoms cables cross the estuary, although one does come ashore at Saunton (Bill Newcombe, pers. comm.).

The development of the Atlantic Array offshore wind farm may increase the cabling across the estuary bed. The cables from the Array will be routed to the existing substation at Alverdiscott, after coming ashore at one of three possible sites: Woolacombe, Saunton or Cornborough (McMahon and Golding, 2010). For landfall at either Woolacombe or Saunton, overhead or buried cabling is being considered for crossing the Taw, as is the construction of a new substation at Yelland, to reduce onward cabling to Alverdiscott. Landfall at Cornborough would require cables to cross the Torridge, but at some distance south of the estuary area.

I.5 Cultural Services

Recreation and Tourism

In the South West, 13% of people enjoying some form of sporting activity participate in outdoor water-based activities (compared to 8% nationally), of which the most popular are outdoor swimming, surfing and inland fishing (University of Brighton et al, 2009a). This figure is expected to continue to rise. With the inclusion of activities such as walking and visits to the beach, where water is a feature of the landscape rather than the focus of a specific activity, the proportion of adults in the South West spending at least some of their leisure time enjoying water rises to 40% (University of Brighton et al, 2009b).

There have been few detailed studies of recreational use of the Taw Torridge, and those that have been undertaken have focused on non-powered watersports and on the Tarka Trail, a 180 mile foot and cycle path, with sections including coastal stretches and both banks of the estuary. A survey of Tarka Trail users in 1994 showed that 24% were from the local area, a further 22% were from the wider south west, and 21% came from London and the south east (Trowbridge, 1995). This high proportion of users from southern parts of England is supported by information from the outdoor activity centres who rarely attract UK clients from the area north of a line between Birmingham and East Anglia (Barry Kaufman-Hill; Matt Upward; Shaun Parker pers, comm.).

An indication of the relative popularity of different recreational activities taking place within the estuary can be gleaned from the membership of local clubs and organisations (Figure 54), which suggests that angling and sailing are particularly well subscribed. This approach has limitations, as some popular activities (for example walking, bird watching, swimming) are not represented at all, and actual levels of involvement in the activities that are included will be underestimated, as club membership is not compulsory for participation in any activity. Club membership is likely to be most representative of actual participation levels for organisations where membership confers some particular advantage not available to individuals, such as access to equipment, storage facilities, moorings or privately owned foreshore areas. Additional recreational activities such as surfing and diving also take place in the wider Bideford Bay area although not within the estuary itself.

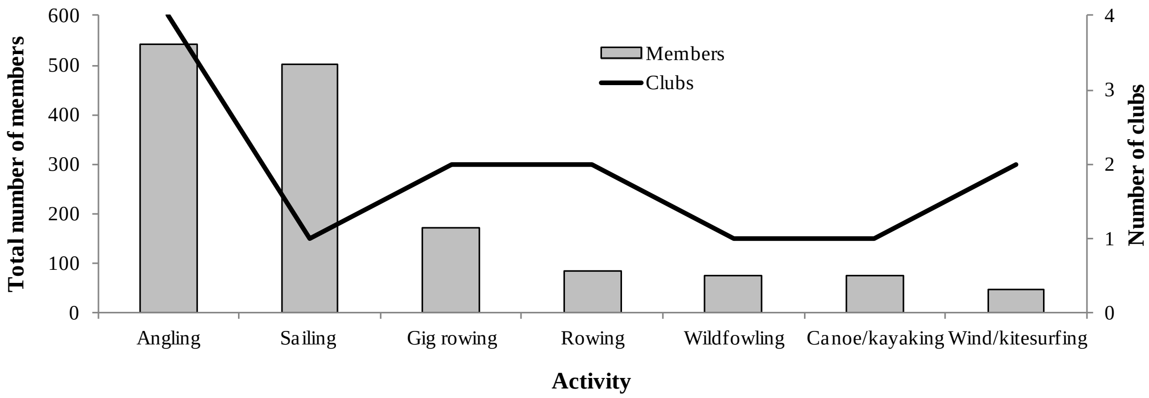

Figure 54. Membership levels for recreational clubs and organisations using the estuary

Land-based coastal margin activities

A visitor survey undertaken on the Tarka Trail during the summer of 1994 (Trowbridge, 1995) showed that the coastal and river/estuary sections of the trail were the most popular (compared to the Exmoor area and southern rural parts of the trail), and that most visitors were using the trail to explore local villages and pubs and to learn something about wildlife. However, few cited a specific activity related to the local wildlife as their main purpose in using the trail. Instead, 46% of users cited walking, 31% cycling and 10% dog walking.

Other areas in the estuary are also popular with walkers and dog walkers, particularly the extensive Braunton Burrows dune system, the neighbouring Saunton Sands beach, and Instow beach, which lies within the estuary. The more exposed locations of Westward Ho! and Saunton Sands beaches also attract kite buggies and kite landboarders, although the latter site is only used outside of the summer season (Craig Wannacott, pers. comm.). As an indication of the level of interest in these activities, the Westward Wind Kite Club has about 40 members, including those who regularly travel from Tiverton, Taunton, Plymouth and even Swindon (Craig Wannacott, pers. comm.).

Other uses of the coastal margin areas include the two golf courses on Braunton and Northam Burrows (Figure 55).

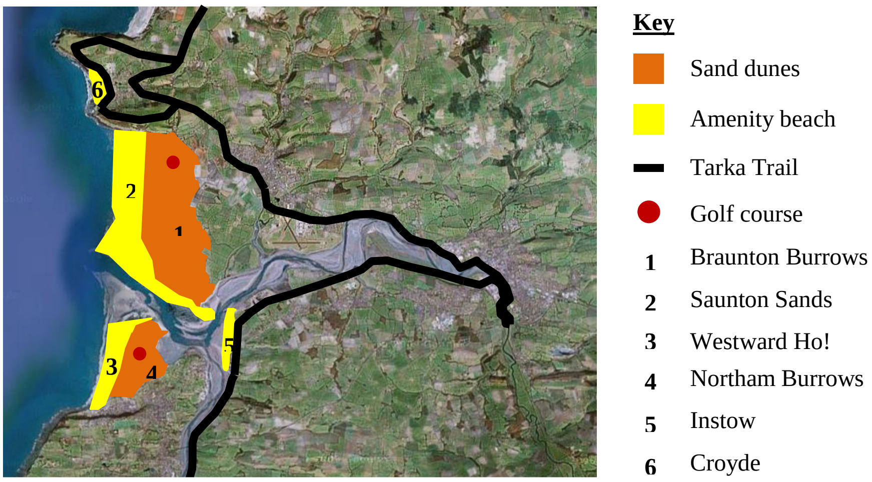

Figure 55. Areas of high amenity value for non water-based recreation in the coastal margin

Pleasure Craft

Small vessels carrying up to 12 passengers operate in the estuary, offering pleasure trips including bass angling, bird watching and historical tours, or operating as ferry services. North Devon District Council have not issued any pleasure craft licences since 2007 (Phil Fitzsimons, pers. comm.), while Torridge District Council issue two or three licences per year for pleasure craft based out of Appledore and working in the Taw Torridge estuary waters (Tony Nicholls, pers. comm.). The larger *MV Oldenburg* also operates occasional jazz cruises along the Torridge on summer evenings.

Swimming

Westward Ho!, Saunton Sands and Instow are also designated bathing beaches, as is Croyde, located to the north of Saunton Sands. Westward Ho! is a Blue Flag Beach, recognising the quality of bathing water as well as adherence to wider management, education and safety standards (Blue Flag, 2010). Bathing water quality is a serious issue at Instow, which has been given an overall rating of 'Poor' for 15 summer seasons since 1990, meaning that fewer than 95% of the samples taken over the course of the season have met the mandatory standard (Environment Agency, 2010h). During the same period, Westward Ho! was rated Poor only in 1998 and 1999, Saunton in 1998 and Croyde did not received a single Poor rating (Figure 56). Bathing water classifications are currently undergoing revision in preparation for the new Bathing Water Directive which comes into force in 2015 (Environment Agency, 2010h).

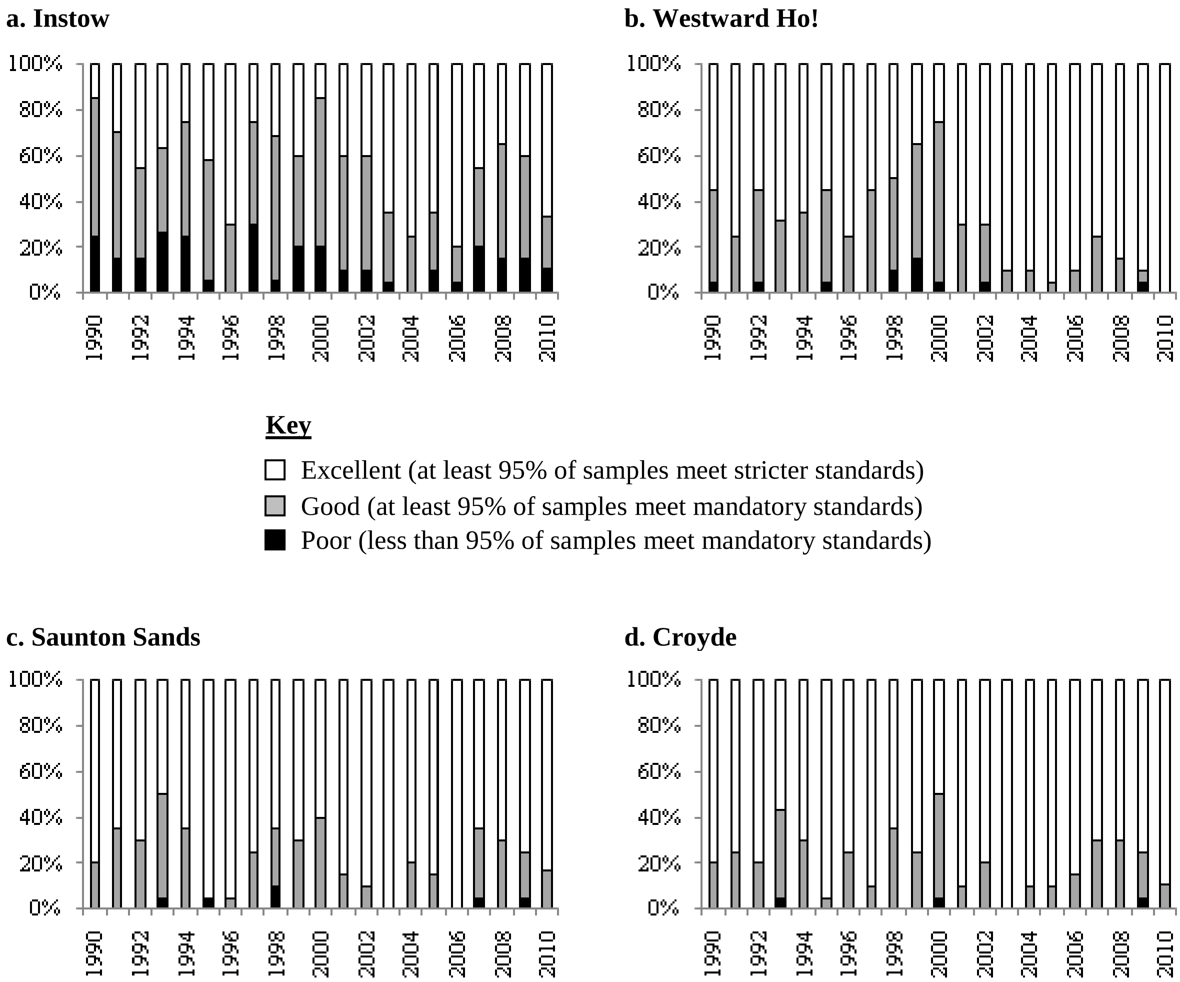

Figure 56. The percentage of samples within each bathing water classification for designated bathing beaches in the Taw Torridge estuary and neighbouring coast for the period 1990-2010.

Watersports

It has been estimated that watersports directly contribute £80 million to the turnover of businesses in northern Devon, with 149,000 visitors attracted, at least in part, by local watersports opportunities (Abell and Bromham, 2009). A wide range of different watersports take place within the estuary and surrounding area (Figure 57), information about which has been obtained from nine local watersports clubs and four activity centres. While there is a concentration of activity during the summer season (particularly July and August), watersports continue all year. Outdoor activity centres remain open for except for short closures in December/January, with off-season clients often colleges seeking a defined social or skills development outcome for their students (Barry Kaufman-Hill pers. comm.). Local clubs and individuals also use the area all year round, particularly on weekends and light evenings.

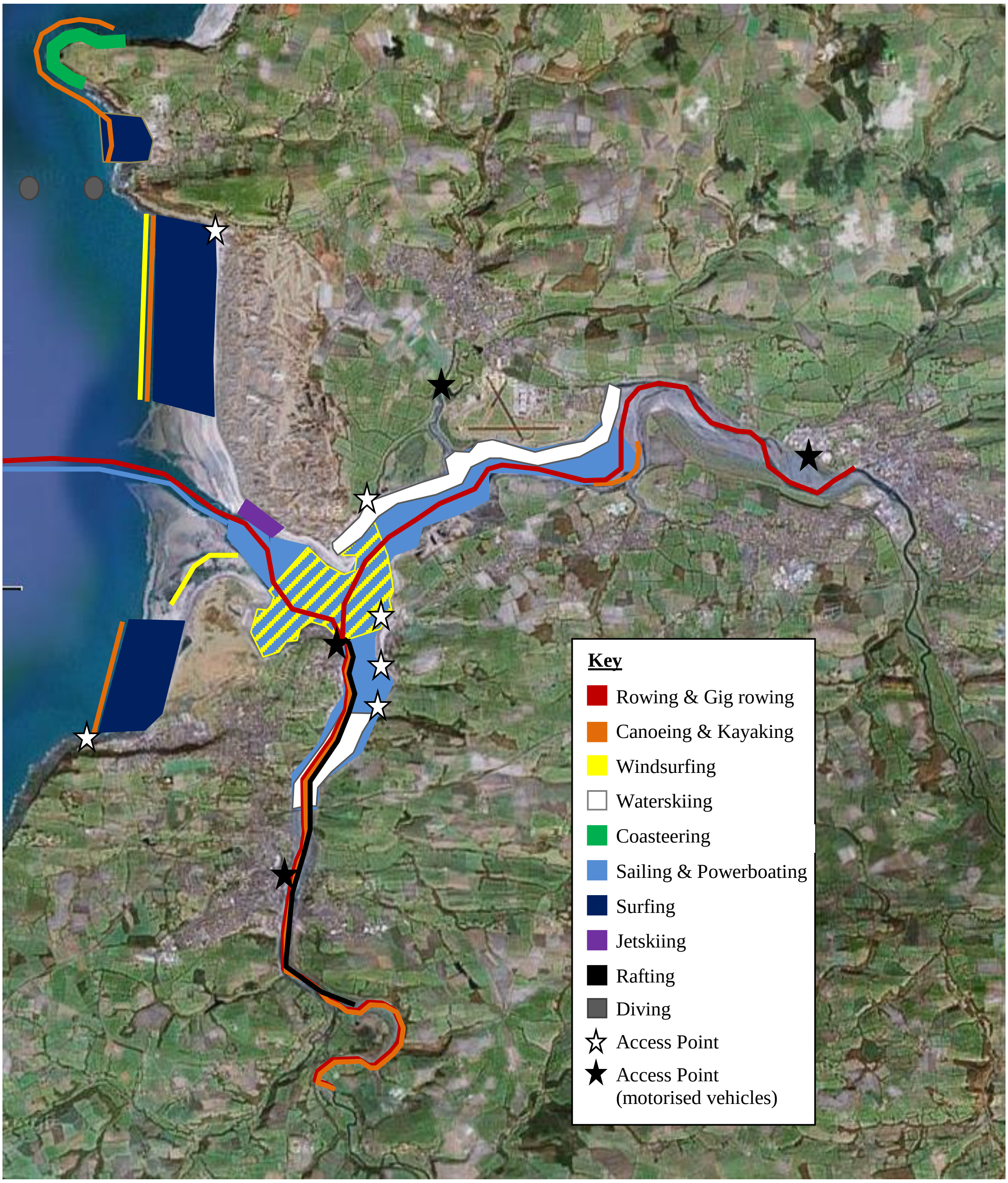

Figure 57. The principal areas of the estuary and surrounding coastline used for different watersports activities

At sites within the estuary, watersports tend to be restricted to the period around high tide, as the low water levels and increased current speeds reduce opportunities outside of these times. The bar at the estuary mouth has been described as one of the most dangerous in the country, and large swell waves can close the estuary (Tony Pratt, pers. comm.). Also, the navigable channel in this area is narrow and often has breaking surf on either side. These difficult conditions limit access between the estuary and Bideford Bay.

Surfing is one of the larger watersports sectors, generating a total annual economic value of £52 million, with local surfers and visitors to the area spending about the same annually (£1,358 and £1,121 respectively), as local surfers spend less each visit but make more trips (Abell and Mallett, 2008). The popularity of surfing compared to other watersports is indicated by the relative number of clients undertaking different sports at outdoor activity centres. At the larger residential centres, 50-70% more customers go surfing each year compared to the next most popular watersport, while at the smaller centres this can increase to more than twice as many surfing trips than other activities combined (Barry Kaufman-Hill pers. comm., Matt Upward pers. comm., James Lewis pers, comm.). Also, surfing-related businesses (equipment sales and hire, tuition, fashion outlets, manufacturing) vastly outnumber similar industries dedicated to other watersports.

There are no surfing sites within the estuary itself, but surfers regularly use beaches just outside the mouth, particularly Saunton Sands and, less frequently, Westward Ho!. Croyde is the most frequently surfed beach in northern Devon area, followed by Woolacombe and Putsborough (to the north of Baggy Point, and so just outside the area defined by this study) (Abell and Mallett, 2008).

There is a subaqua club based in Appledore, with 55 members, but they do not dive the estuary itself, due mainly to the large tidal range, high levels of wave exposure at the estuary mouth and the extensive boating activity. The club occasionally dive Asp Rock and Downe End off Croyde Bay, but the focus of their diving is the east coast of Lundy island. Coasteering also takes place on Baggy Point.

Sailing, kayaking, gig rowing and windsurfing all take place within the estuary itself as well as at sites beyond the bar. Rowing and rafting are limited to the calmer environment of the estuary. Sailors rarely travel further upstream than Fremington on the Taw, as the depth of the channel towards Barnstaple has been reduced by siltation. The old bridge at Bideford marks the limit on the Torridge, as masted boats cannot pass beneath it. The North Devon Yacht club has a strong cadet section, which makes up 25% of its membership, and a particular focus of club activity is the cadet training which takes place over 3 weeks in the summer and involves about 120 young sailors aged 10 and over. A similar number of young people sail with one the activity centres each year, usually in the Taw between Crow Point and Chivenor. The yacht club also organises regular races, and has a small group of 'country members', who live more than 30km from Instow, but who still sail relatively frequently with the club. Many of these members come from the Bristol area, and other sailors come from further afield to participate in the annual open week for visitors.

Rafting trips are organised by one of the activity centres and take place on the Torridge between Littleham Mere and Appledore. Rowing also tends to take place within the Torridge between Appledore and Weare Giffard, although one of the pilot gig clubs does sometimes row up the Taw to Barnstaple. The length of the Torridge is also more heavily used by local kayakers, although some areas of the Taw, such as near Fremington, are also used. Kayaking and canoeing also takes place between Westward Ho! and Saunton, and around Baggy Point. Windsurfing and kitesurfing tends to be focused in the area between Crow Point, Instow and Appledore. Wind and kite surfers also use Northam Burrows or Saunton Sands, and both beaches have been the site of special events.

The estuary is also used for jetskiing and waterskiing (as well as 'ringoing' on towed inflatable rafts). Conflicts between different estuary user groups led stakeholders to develop a voluntary code of conduct, which restricts these two activities to designated areas. Jetskiing is permitted near Airy Point close to the mouth of the estuary, while water skiing and similar activities are allowed on the Taw between Crow Point and Heanton and on the Torridge between the Appledore shipyard and the new bridge. There is a 6 knot speed limit upstream of the new Barnstaple bridge, within Fremington Pill and the Caen and in much of the Torridge (except for the designated waterskiing area). This is mostly voluntary, and is only compulsory in the Bideford harbour authority area between the two bridges.

A further use issue is that of slipway access. There are few locations from which motorised craft can be launched: Bideford Quay, for example, lacks low water access, requiring craft to be carried down the steps at these times. The Churchfield slip at the end of Appledore Quay is the easiest launching site and so becomes very congested during the summer season. Warden schemes do operate in the summer to ensure that slipway users are registered and insured.

Some options for expanding watersports opportunities within the Taw Torridge have been proposed, including the repeated (and repeatedly rejected) submission of formal planning applications for a marina at Knapp House between Appledore and Bideford. Less formally, members of the public have also submitted to the local press their views in support of developing more opportunities for watersports out of Barnstaple – a reflection of the limited current use of the Taw (North Devon Journal, 2008).

Nature watching

a) Otters

Otters (*Lutra lutra*), make extensive use of Taw and Torridge rivers (Crawford, 2010), although their presence in the estuary itself was not quantified, as it was outside the boundary of that study. Otters are often seen at Beam Weir near Torrington (about 2km upstream of the tidal limit of the Torridge), as well as within the estuary itself (Paul Carter pers. comm.).

b) Marine Mammals

There is a breeding population of grey seals (*Halichoerus grypus*), on Lundy island (Davies, 1998), and small numbers of seals are seen each year in the area between Westward Ho! and Baggy Point, and within the estuary. One report records a seal reaching as far upstream as Ashford, near Barnstaple (Devon Biodiversity Records Centre, unpublished data). Common seals (*Phoca vitulina*) have also been seen in the estuary (TTEP, 1998). Harbour porpoise (*Phocoena phocoena*), bottlenose dolphins (*Tursiops truncates*), common dolphins (*Delphinus delphis*) and orcas (*Orcinus orca*) have been observed close to shore in Bideford Bay (DBRC, 2010). Dolphins and porpoises also enter the estuary, and are seen occasionally close to Instow.

c) Birds

The Taw Torridge estuary rates as a principal site for non-breeding waterbirds, as it supports more than 10,000 waterbirds each year. The five year average of over 14,500 birds places the estuary 69th in the list of principal UK wetlands (Calbrade et al., 2010), although the Taw Torridge is considerably smaller than many sites that support a greater abundance of waterbirds. The Taw Torridge has no internationally important populations of waterbirds, although Ringed Plover (*Charadrius hiaticula*) and Sanderling (*Calidris alba*), occur in sufficient numbers to be considered nationally important (Calbrade et al, 2010). The Taw Torridge also supports 10-15% of the southwest region's Lapwing (*Vanellus vanellus*) Curlew (*Numenius arquata*), and Redshank (*Tringa tetanus*) (Thaxter et al., 2010).

Detailed assessment of the bird populations has been made using data supplied by the Wetland Bird Survey (WeBS), a partnership between the British Trust for Ornithology, the Royal Society for the Protection of Birds and the Joint Nature Conservation Committee (the latter on behalf of the Council for Nature Conservation and the Countryside, the Countryside Council for Wales, Natural England and Scottish Natural Heritage) in association with the Wildfowl and Wetlands Trust. This data is based on monthly counts made by volunteers, usually on high tide roosts.

88 waterbird species were observed in the Taw Torridge over the five seasons from 2004/05 to 2008/09, of which 29 species (33%) have some presence within the estuary all year (Table 43). The most abundant species are Golden Plover (*Pluvialis apricaria*), Black-headed Gull (*Larus ridibundus*), Lapwing (*Vanellus vanellus*), Oystercatcher (*Haematopus ostralegus*), Curlew (*Numenius arquata*) and Dunlin (*Calidris alpine*). The migratory nature of most waterbirds means that the numbers of individuals vary over the course of any given year, and the highest five-year average monthly count for each of these species, exceeded 1,000 individuals (Figure 58). It should be noted that Lapwings and Golden Plovers also use nearby terrestrial habitats (Musgrove et al. 2003), which may be a factor in determining their local abundance.

Table 43. The waterbird species recorded in the Taw Torridge estuary by the Wetland Bird Survey between 2004/05 and 2008/09, indicating those species present: (a) all year in at least one section of the estuary, (b) for part of the year, (c) in low numbers, with a peak five-year average monthly count of 1-10 individuals, and (d) only very rarely, with a peak five-year monthly count of less than one individual

a. All Year
Mute Swan, *Cygnus olor*
Canada Goose, *Branta Canadensis*
Shelduck, *Tadorna tadorna*
Wigeon, *Anas Penelope*
Teal, *Anas crecca*
Mallard, *Anas platyrhynchos*
Little Grebe, *Tachybaptus ruficollis*
Cormorant, *Phalacrocorax carbo*
Little Egret, *Egretta garzetta*
Grey Heron, *Ardea cinerea*
Moorhen, *Gallinula chloropus*
Oystercatcher, *Haematopus ostralegus*
Ringed Plover, *Charadrius hiaticula*
Golden Plover, *Pluvialis apricaria*
Grey Plover, *Pluvialis squatarola*
Lapwing, *Vanellus vanellus*
Sanderling, *Calidris alba*
Dunlin, *Calidris alpine*
Black-tailed Godwit, *Limosa limosa*
Bar-tailed Godwit, *Limosa lapponica*
Curlew, *Numenius arquata*
Common Sandpiper, *Actitus hypoleucos*
Redshank, *Tringa tetanus*
Turnstone, *Arenaria interpres*
Black-headed Gull, *Larus ridibundus*
Lesser Black-backed Gull, *Larus fuscus*
Herring Gull, *Larus argentatus*
Great Black-backed Gull, *Larus marinus*

d. Very Rare/infrequent (<1/year)
Black Swan, *Cygnus atratus*
Chinese Goose, *Anser cygnoides*
Bean Goose, *Anser fabalis*
Greenland White-fronted Goose, *Anser albifrons*
Bar-headed Goose, *Anser indicus*
Ruddy Shelduck, *Tadorna ferruginea*
Muscovy Duck, *Cairina moschata*
Garganey, *Anas querquedula*
Pochard, *Aythya farina*
Ring-necked duck, *Aythya collaris*
Great Northern Diver, *Gavia immer*
Red-necked Grebe, *Podiceps grisegna*
Laughing Gull, *Larus atricilla*
Ring-billed Gull, *Larus delawarensis*
Iceland Gull, *Larus glaucoides*
Glaucous Gull, *Larus hyperboreus*
Gull-billed Tern, *Gelochelidon nilotica*

b. Part year
Dark-bellied Brent Goose, *Branta bernicla bernicla*
Pintail, *Anas acuta*
Shoveler, *Anas clypeata*
Spoonbill, *Platalea leucorodia*
Knot, *Calidris canutus*
Snipe, *Gallinago gallinago*
Whimbrel, *Numenius phaeopus*
Greenshank, *Tringa nebularia*
Kittiwake, *Rissa tridactyla*
Mediterranean Gull, *Larus melanocephalus*
Common Gull, *Larus canus*
Sandwich Tern, *Sterna sandvicensis*
Common Tern, *Sterna hirundo*

c. Rare/infrequent (1-10/year)
Greylag Goose, *Anser anser*
Barnacle Goose, *Branta leucopsis*
Light-bellied Brent Goose, *Branta bernicla hrota*
Gadwall, *Anas strepera*
Tufted Duck, *Aythya fuligula*
Eider, *Somateria mollissima*
King Eider, *Somateria spectabilis*
Common Scoter, *Melanitta nigra*
Goldeneye, *Bucephala clangula*
Red-breasted Merganser, *Mergus serrator*
Goosander, *Mergus merganser*
Red-throated Diver, *Gavia stellata*
Great Crested Grebe, *Podiceps cristatus*
Shag, *Phalacrocorax aristotelis*
Water Rail, *Rallus aquaticus*
Coot, *Fulica atra*
Little Stint, *Calidris minuta*
Curlew Sandpiper, *Calidris ferruginea*
Purple Sandpiper, *Calidris maritime*
Ruff, *Philomachus pugnax*
Green Sandpiper, *Tringa ochropus*
Spotted Redshank, *Tringa erythropus*
Little Gull, *Larus minutes*
Little Tern, *Sterna albifrons*
Arctic Tern, *Sterna paradisaea*
Black Tern, *Chlidonius niger*
Kingfisher, *Alcedo atthis*

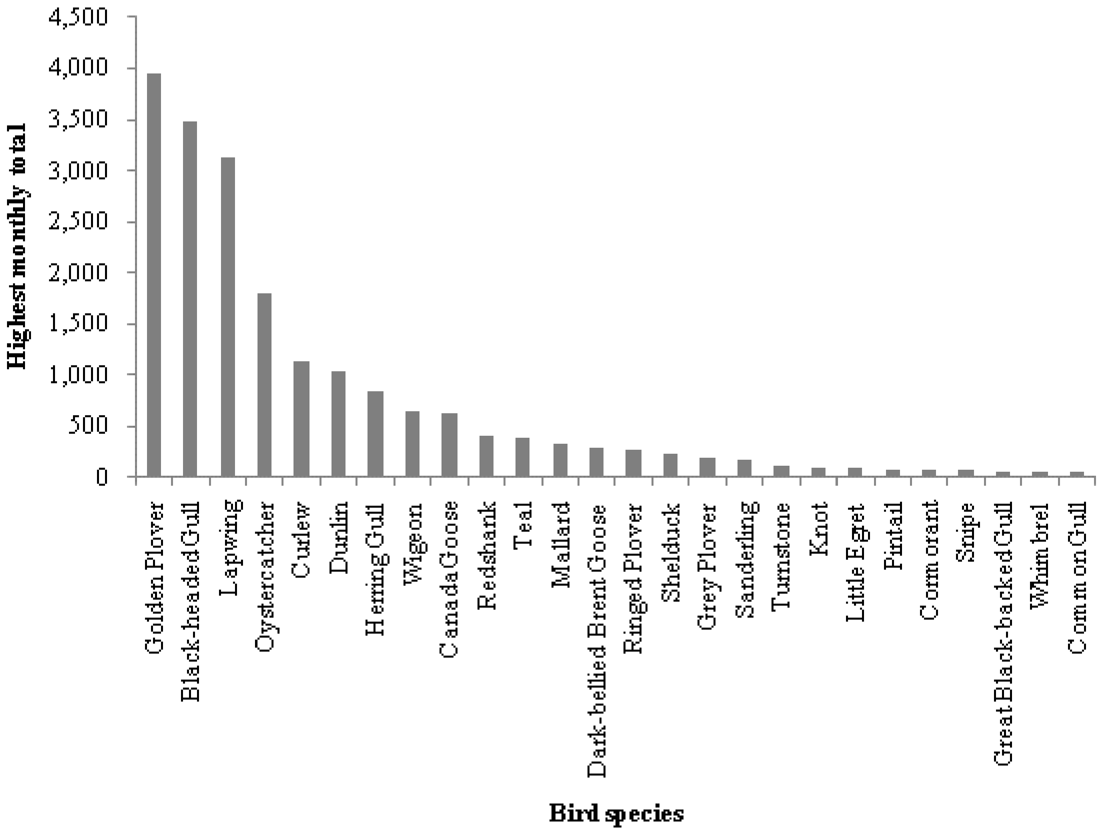

Figure 58. The highest five-year average monthly count for the most abundant bird species observed in the Taw Torridge estuary between 2004/05 and 2008/09

The highest five-year average monthly count did not exceed 50 individuals for 70% of species recorded in the Taw Torridge, but consideration of absolute abundance requires caution, as the likely density of individuals varies according to the requirements, and population status, of the different species. For 53% of the species observed on the estuary fewer than 10 individuals were present. Birdwatchers are, of course, interested in the less common visitors to an area, and the Taw Torridge has been notable recently for the presence of King eider (*Somateria spectabilis*) and Spoonbill (*Platalea leucorodia*), which are seen only rarely anywhere in the UK (Calbrade et al., 2010).

The Wetland Bird Survey for the Taw Torridge is based on aggregated counts for different sections of the estuary. These sectoral counts show that the upstream areas of the Taw support the highest numbers of waterbirds (Figure 59). The south shore section from Fremington to Barnstaple has a peak five year count of more than double the number of individual birds found elsewhere in the estuary. Golden Plovers, Lapwings and Black Headed Gulls are the most abundant birds in this sector, which supports about half the total estuary population of the former two species. Lapwing are regionally important species, as are Redshank and Curlew. These latter two species are also particularly abundant between Fremington and Barnstaple and also in the adjacent sector, extending westwards to Isley. There are also large numbers of Redshank upstream of Bideford in the Torridge. Bird numbers in the Torridge are generally relatively low, principally because the Torridge is confined within a narrow rocky channel, which constrains the development of suitable waterbird habitat. Ringed Plovers and Sanderling, which occur in nationally important numbers, are found mainly on the north shore of the Taw between the White House and Heanton.

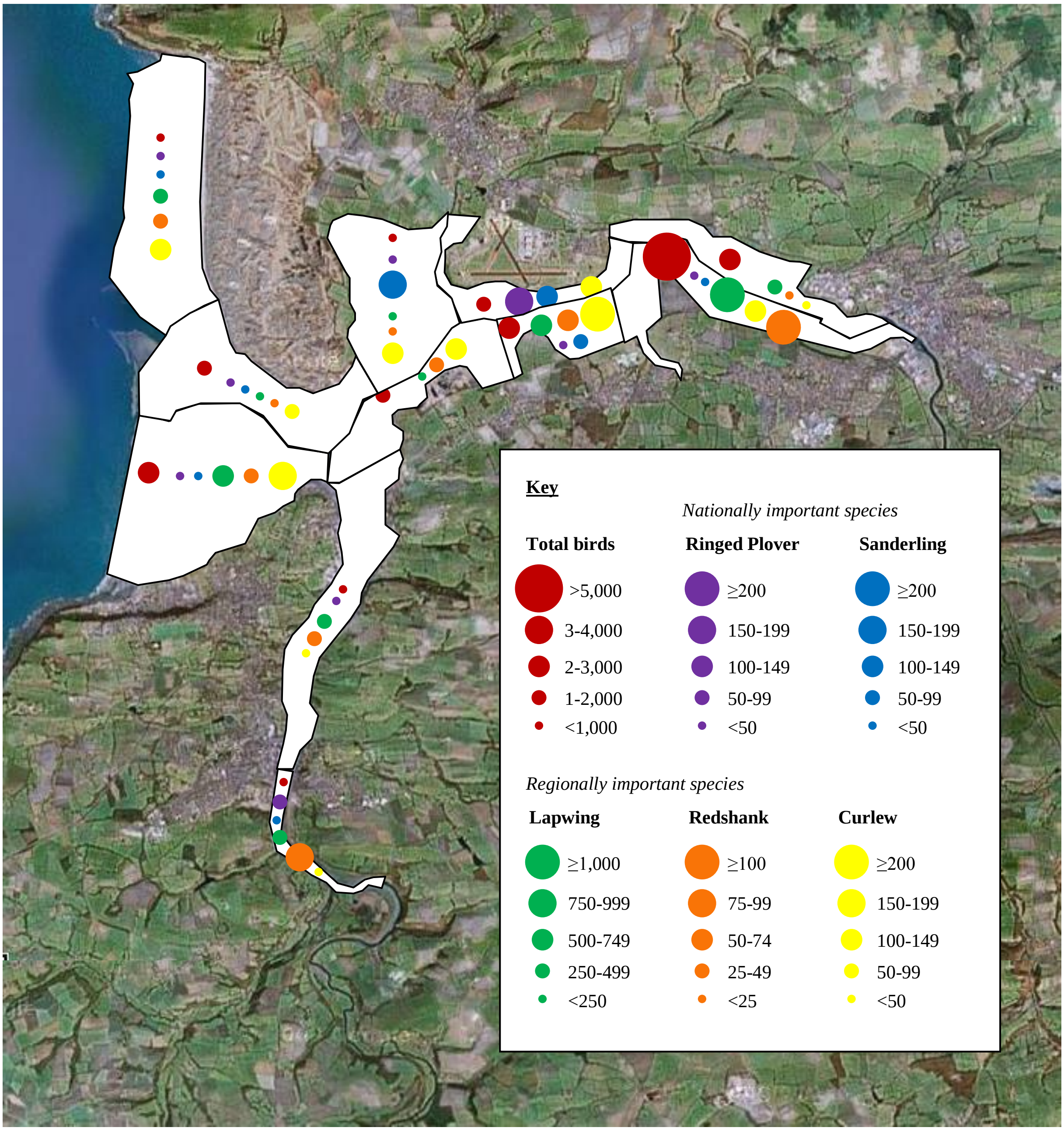

Figure 59. The relative abundance of nationally and regionally important waterbird species in the different sectors of the Taw Torridge estuary (The Wetland Bird Survey 2008/09, unpublished data)

The abundance of birds in different estuary sectors determined by the Wetland Bird Survey core counts is based mainly on the presence of birds in their high tide roosts. Low tide counts are a better indication of the use of different feeding areas, but these were only completed for the Taw

Torridge during the 1994/95 winter season. That study reinforced the broad conclusions that can be drawn from the core count data, namely that the important areas for waterbirds are found either side of Penhill Point, on the northern edge of Northam Burrows, and in the upper reaches of the Torridge (Musgrove et al. 2003). Also, while the core count data shows that Ringed Plovers tend to use the Taw between the Caen and Heanton for roosting at high tide, they low tide counts suggest that their preferred feeding grounds are near the mouth of the estuary.

There is evidence that the numbers of waterbirds on the Taw Torridge are falling. The estuary was identified as a potential Special Protection Area under the Birds Directive, but this status was not conferred due to the continued decline in the number of overwintering birds (TTEP, 1998). Assessment has been made of the trends for individual, regionally important species, and these show that, despite the inherent variability in the population size, the number of Curlews declined consistently between 1994/5 and 2007/8 and total numbers have reduced by 45% (Thaxter et al. 2010). This decline is more marked in the Taw Torridge than in regional or national trends. Lapwing may also be showing some recent decline, while Redshank numbers remain broadly consistent (Thaxter et al. 2010). Both pictures reflect regional and national trends.

None of the bird species present in the estuary are classified at a global level as Endangered, Vulnerable or Near Threatened according to the IUCN Red List, but some are considered to be at risk within the UK. The fourth review of the population status of UK breeding birds red-listed Lapwing (*Vanellus vanellus*), Common Scoter (*Melanitta nigra*), Whimbrel (*Numenius phaeopus*), Black-Tailed Godwit (*Limosa limosa*), Ruff (*Philomachus pugnax*) and Herring gull (*Larus argentatus*), highlighting the serious decline in their populations (Eaton et al. 2009). A further 53 species found in the Taw Torridge were placed on the amber list by that review, reflecting a lesser threat to their populations nationwide. Lapwing and Common Scoter, together with Curlew (*Numenius arquata*) and Dark-bellied Brent Goose (*Branta bernicla bernicla*) are listed as Species of Principal Importance in England under the Natural Environment and Rural Communities Act 2006, and have Biodiversity Action Plans in place to promote their conservation. Additional UK and European legislation is relevant to many of the bird species which use the Taw Torridge: 80% of waterbirds that visit the estuary are mentioned under some form of protective scheduling.

The importance of the estuary as a habitat for migratory and overwintering birds was one of the core criteria in the notification of the estuary as a Site of Special Scientific Interest in 1981. There are also a number of bird reserves on private land (Figure 60), principally the RSPB reserve at Isley Marsh and the neighbouring Home Farm Marsh reserve owned by the Gaia Trust. The Devon Birdwatching and Preservation Society (DBWPS) also owns and manages a reserve at Bradiford outside Barnstaple, and manages a further site at Velator on land leased from South West Water.

Figure 60. Bird reserve areas

There appears to have been little effort directed towards quantification of the actual levels of birdwatching in the estuary. About 75 members of the public submit bird observation records to the RSPB and DBWPS, but this represents an unusually high level of commitment. For example, only about 12 of the 42 registered volunteer wardens at Isley Marsh submit observation data (Nicky Hewitt, pers. comm.) as do about 60 DBWPS members (the organisation has twice that number of local members) (Julia Harris pers com.; Ian Farrell pers. comm.). At the other end of the scale, 2,300 people in the local area are members of the RSPB (Julie Plater, pers. comm.). While this shows considerable interest locally in birdlife and its conservation, it gives no indication at all of the number of people who go birdwatching on the estuary. These figures also exclude the interest in birds held by visitors to the estuary. During a survey into use of the Tarka Trail, less than 2% of respondents cited birdwatching as the main purpose of their visit (Trowbridge, 1995), but it is quite likely that birdwatchers would avoid the Trail given its popularity with dog-walkers and cyclists and the likely disturbance these activities would cause to birds. Visitor numbers are not currently monitored at Isley or Harm Farm Marsh as neither reserve is manned (Alison Vaughan, pers. comm.; Nicky Hewitt, pers. comm.).

Rockpooling

A further, but entirely unquantified, recreational use of the estuary's marine life is through rockpooling (the discovery and observation of beach marine life). The main amenity beaches are predominantly sand, but there are rocky shores at both Appledore and Instow.

Wildfowling

Recreational use of the estuary's waterbirds is not restricted to watching them. The Taw and Torridge Wildfowling Club holds the lease on 650ha of foreshore the Taw, within the area from Pottington to Instow and across to Appledore on the south shore, and to just seaward of Crow Point on the north shore. Penhill Marsh is one of the more popular sites for fowling, while club rules prohibit shooting in other areas, such as sites adjacent to the Isley Marsh RSPB reserve.

Currently, the club has 75 members, and its maximum membership is restricted to 100: one of several measures designed to prevent excessive pressure on the bird populations. The shooting season runs from 1 September to 20 February, although shooting tends not to begin until October, due to the high levels of tourism that continue into September and disturb the birds. Shooting is also not permitted on Sundays. The total number of visits to the estuary made by club members is usually less than 150 over the course of the season, with each visit lasting an average of 2-3hours. The main quarry is Canada Geese, Wigeon, Teal and Mallard, and the average bag is just over one duck or goose per visit.

Angling

Angling takes place throughout the estuary, for salmon, sea trout and marine fish. There are at least four angling clubs in the local area whose members engage in sea angling, usually combined with coarse and game fishing. The clubs have a combined membership of over 500, although the 300 members of the largest club (the Bideford and District Angling Club) are drawn from a very wide area and focus mostly on coarse fishing at locations throughout the south west region. The other clubs who provided information for this study were the Barnstaple and District Angling Association, the Barnstaple Rod ‘n’ Reelers and the Triple Hook S.A. Club.

The salmon season extends from 1 March to 30 September, while that for sea trout is slightly shorter, starting on 15 March (Environment Agency, 2009a). The fishery is licensed, and licence holders are required to supply catch data. More fish are caught in the Taw than the Torridge, and the rod fishery is more important (in terms of total numbers of fish caught) than the net fishery (Figure 61). During 2008, peak salmon catches were in August/September, and in June/July for Sea Trout.

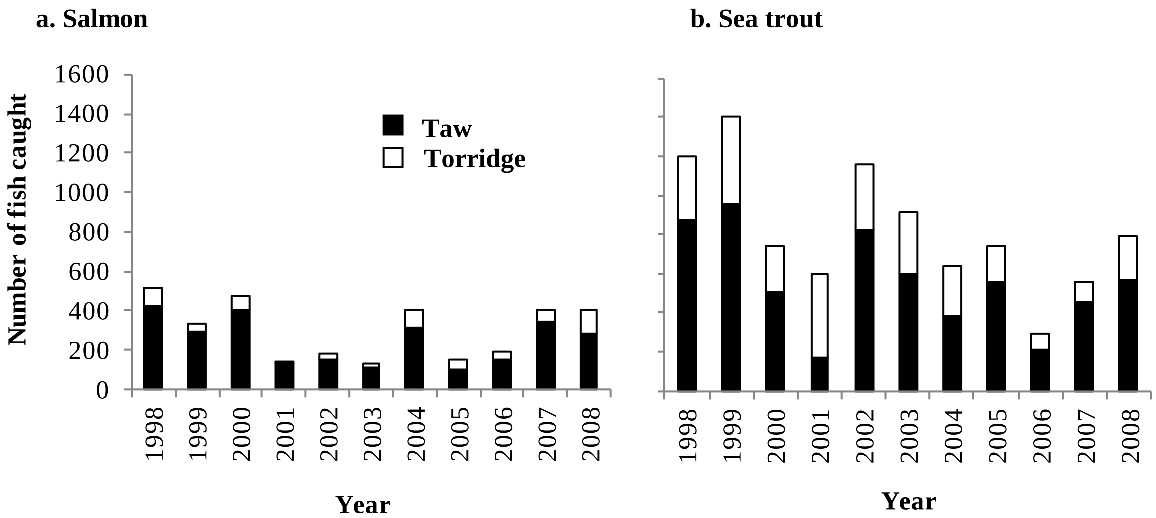

Figure 61. Total annual landings of salmon and sea trout from the Taw and Torridge reported by rod licence holders between 1998 and 2008 (data from the Environment Agency, 2009a).

In addition to the closed season, the rod and line fishery is also controlled by bag limits and method restrictions, and it is an offence to sell rod-caught salmon and sea trout, although these can be used for personal consumption (Environment Agency, 2010e). All salmon caught by rod and line before 16 June must be released, but high levels of releases continue throughout the season (Figure 62). 65% of rod-caught salmon and 58% of sea trout were released in 2008 (up from a national average of 8% released in 1993) and the catch per licence day was 0.1 fish for salmon and 0.2 fish for sea trout (Environment Agency, 2009a).

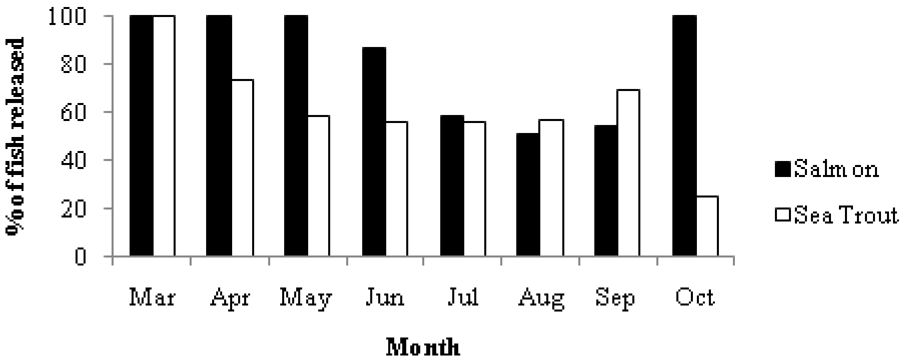

Figure 62. The percentage of salmon and sea trout from the Taw and Torridge which are released after capture (data from the Environment Agency, 2009a)

The mean weight of a salmon landed in the Taw in 2008 was 3.8kg, compared to 3.3kg from the Torridge, while the mean weight of a sea trout caught in either river was 0.9kg (Environment Agency, 2009a). However, when considering modal weight class, 65% of salmon in caught in the Taw (and 59% from the Torridge) weighed less than 3.6kg. 50% of sea trout from the Taw (55% from the Torridge) weighed between 0.45kg and 1.8kg (Figure 63). About 60% of the fish caught in either river were grilse (one-sea-winter fish) (Environment Agency, 2009a).

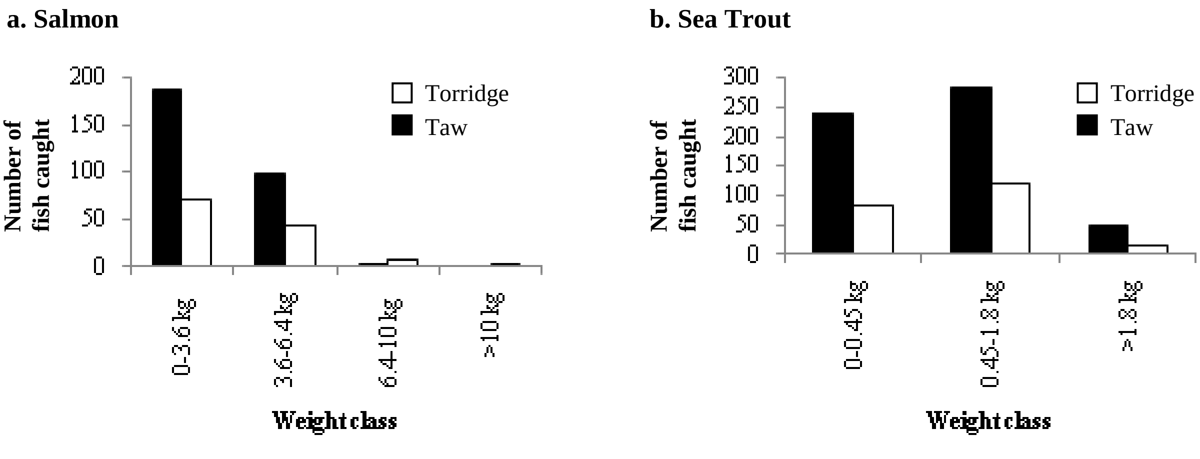

Figure 63. The weight classes of rod caught salmon and sea trout from the Taw and Torridge during 2008 (data from the Environment Agency, 2009a)

Sea angling is popular within the estuary and off the beaches between Westward Ho! and Croyde. The sport does not require a licence (or the payment of associated fees) and is less stringently regulated than game fishing, which accounts, to some extent, for its popularity with anglers. Catches are not monitored, but as with salmon and sea trout fishing, catch and release is encouraged and much of the sea angling catch is returned.

From about September to February, the majority of effort within the estuary is concentrated on fishing for flounder (*Platichthys flesus*) which takes place primarily near Barnstaple and Bideford. In the summer, the upper tidal reaches of the estuaries (as far as the tidal limit at Bishops Tawton) are fished for thin-lipped mullet (*Liza ramada*). Bass (*Dicentrachus labrax*) tend to be targeted near the mouth of the estuary and off the beaches at Westward Ho! and Saunton. Cod (*Gadus morhua*) are also caught off the beaches and from Greysands on Norham Burrows. Mackerel (Carangidae), thick-lipped mullet (*Chelon labrosus*), smoothhound (*Mustelus mustelus*), dabs (*Limanda limanda*), pollack (*Pollachius pollachius*), and whiting (*Gadus merlangus*) are also landed by sea anglers.

Catches can vary at different sites depending on the state of the tide, and are not always consistent from year to year. Cod have been declining over the past three or four years, both in terms of numbers visiting the estuary and the size of individuals. Conversely, the mid to late summer seasons of 2009 and 2010 have seen gilthead bream (*Sparus aurata*) in the lower reaches of the estuary, where they had not previously been recorded. Ray (Rajidae) are also once again being caught off the beach at Westward Ho!, having not featured in catches for thirty years. The return has been coincident with water quality improvements.

Cognitive development

Education

a) Field Studies

Studying the marine life on foreshore areas is also a core educational use of the estuary and surrounding coast, as is learning about the geography of the area. The local outdoor activity centres offer biology and geography field studies courses for pupils from Key Stage 2 to A-Level, although, for the two centres providing information, this accounts for 10% or less of their business. The centres use Westward Ho!, Saunton, Braunton Burrows, Croyde and Instow beaches for field studies. Their clients are mostly schools from Devon and the southwest, but schools from further afield do use the centres for residential field studies courses.

b) Schools

Local schools were asked about the frequency of their visits to estuarine and coastal sites, the location and purpose of these visits, and the number of children involved. 61 local schools were contacted by email, of which 23 schools (38%) responded.

18% of the schools responding to the survey never use the estuary or local coastline, and 26% use it less than once per year. Most schools (30%) visit once or twice a year. Of the 26% of schools visiting more than twice per year, the most frequent usage of the area is termly visits by each of the schools five classes. Broadly, the schools closest to the estuary use it the most frequently (Figure 64), but schools will travel up to 30 miles for educational visits. The fieldtrips involve about 1,500 individual children per year, and multiple visits by the same classes brings the total number of ‘child-visits’ in a year to closer to 2,000. If all the schools in the area participate at similar levels to those of the respondents, than the total number of child-visits to the estuary and coastline could exceed 5,000 every year. All age groups from Reception to GCSE are involved in educational visits. These are mostly day or part day trips, but Braunton Burrows is also used for camping trips.

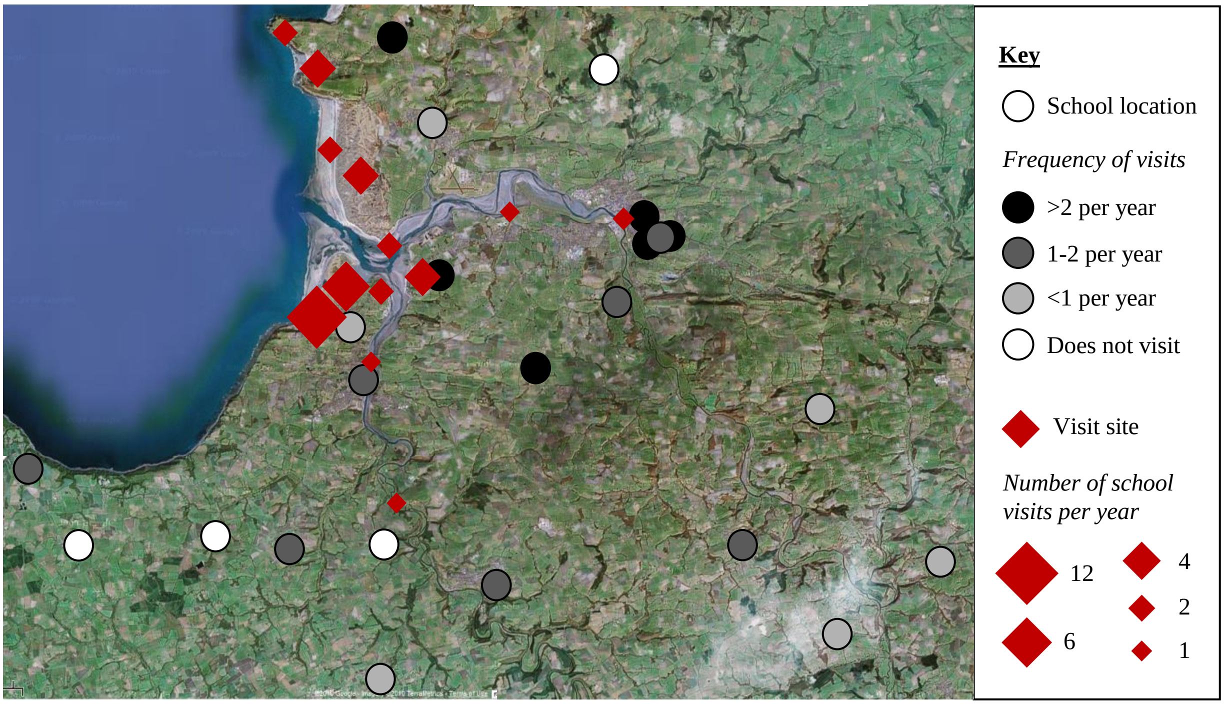

Figure 64. The location of local schools using the estuary, the sites visited and frequency of use

67% of the schools using the area travel to Westward Ho! and 33% visit Northam Burrows. Braunton Burrows, Croyde and Instow are used by 22% of schools. A further eight sites in and around the estuary are used by one or two schools each year (Figure 64). The different areas are used for specific history, geography and science fieldwork and for art projects, but educational use is mainly through cross-curricular activities which incorporate elements of literacy, numeracy, and

ICT, and encourage the development of social skills. In addition to using the area to fulfil curriculum objectives, schools also work on special projects, such as Sea 4 Life, which gives primary school children the opportunity to work with scientists and artists to both better understand their local environment and to use it as creative inspiration. Schools also use the area for sport and fun, including cycling Tarka Trail for cycling and surfing at Croyde and Saunton. The estuary is also incorporated into school life in other ways, such as through naming classes or houses after the rivers and wading birds.

Research

A search of the National Marine Biological Library (NMBL) database in October 2010 identified 83 references concerning the Taw and Torridge rivers and estuary. This suggests that academic interest in these water bodies is similar to that for other small estuaries in the region, although considerably less than for major, well-studied estuaries such as the Severn and Tamar (Figure 65).

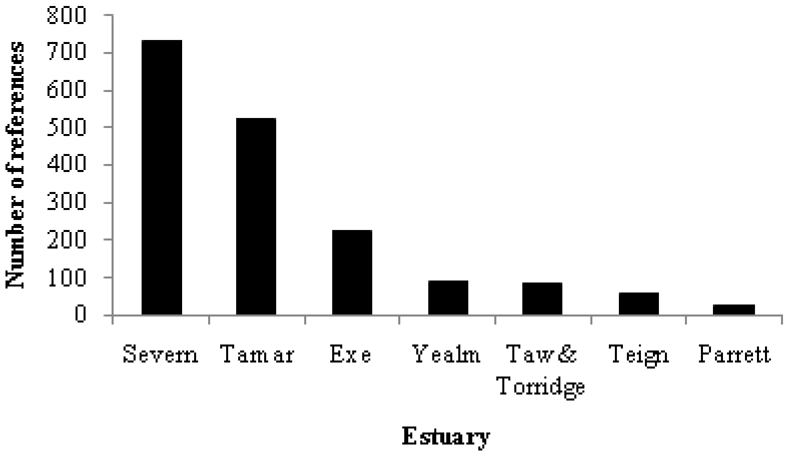

Figure 65. The number of references for selected estuaries in the southwest generated by searches of the National Marine Biological Library database

Its isolated location is one possible reason for the relatively small number of scientific studies concerning the Taw Torridge. Exeter and Plymouth, both about 50 miles away, are the nearest cities with marine research institutions, and both have more local sites at which to conduct estuarine research (hence the higher research output for the Tamar (Plymouth) and the Exe). Also, the Taw Torridge has not been the subject of any major development proposals that have captured regional or national attention in the way that, for example, the Severn Barrage has.

58% of the references generated by the NMBL search are, to at least some degree, peer-reviewed (including papers in journals and proceedings, book chapters and theses), while the rest are reports prepared by a range of agencies and individuals. Nearly 40% of the literature related to the ecology of the estuary (particularly to fish and birds), 23% to water quality and pollution and 22% to studies of sediments, geomorphology and hydrology. The remainder of the literature comprised Catchment Management Plans, two reports related to recreation and one to tidal power. The references date from 1936 to 2010, with 43% of the literature produced in the 1990s.

Any database search underestimates the actual volume of research, as it relies on the key words used to describe the publication that have been chosen by the author or by dedicated librarians. Using different keywords (such as specific site names) to expand the NMBL search generated further references, as did searching the Web of Knowledge database, and using other search terms or databases could further expand the volume of literature detected. The catalogues of Plymouth and Exeter university libraries included additional PhD theses, and further relevant postgraduate research may be stored at other institutions. Undergraduate research may also have been conducted in the Taw Torridge, but no attempt was made to quantify this as it is not routinely listed in university library catalogues. There is also no systematic cataloguing of grey literature, so the volume of information that exists in reports or as unpublished data is similarly impossible to quantify.

Heritage and Identity

Archaeology

The Taw Torridge estuary contains many features of archaeological interest (Figure 66). A comprehensive assessment is contained in Preece (2008), which describes the presence of three ancient sites at Westward Ho!, with the earliest dating from about 4,000BC. Westward Ho! is also the site of a possible submerged forest, and prehistoric hoofprints have been found at Northam (Northern Devon Coast and Countryside Service 2010b). A Bronze Age Stone Row buried under silt at Isley Marsh is one of two scheduled ancient monuments found in the estuary, the other being the Bideford Long Bridge over the Torridge (Planning Policy Unit. 2003; TTEP, 1998). Pottery dating from the 11^{th} or 12^{th} century has been found on Braunton Burrows, on which St Ann's Chapel also stands (Preece, 2008). References to the Chapel date from 1575, although the site's use for Christian worship may be predated by pagan practices.

The shores of the estuary may also be the site of the Battle of Cynwit in 878, a significant victory by the English over Hubba the Dane (Ubbe Ragnarsson), which was instrumental in the rise of Alfred the Great. Local history describes the Danes landing at Appledore and besieging Kenwith Castle (1mile Northwest of Bideford) before finally being beaten at Bloody Corner, Northam (Rogers, 1938; Fielder ,1985). This version of events is reported locally, but other locations in Devon and Somerset have also been put forward as the site of the battle.

Within the estuary itself, Preece (2005, 2008) also describes the remains of several fish weirs. Constructed of stones, posts and nets, fences or a combination, the traps were mostly v-shaped and were used to trap fish on the falling tide. There are references to fishing with weirs in the Taw Torridge during Saxon times, although no remains from that period have been identified. Later references to a weir at Crow Point date from 1573, and weirs were well documented throughout the estuary from the 1600s. At least 18 traps remained in the estuary in the 19th century, although 12 traps on the Torridge alone were decommissioned or destroyed following the Salmon Fisheries Act of 1861. Weir remains are difficult to identify as post remnants may be less than 10cm high and hidden by stones or macroalgae.

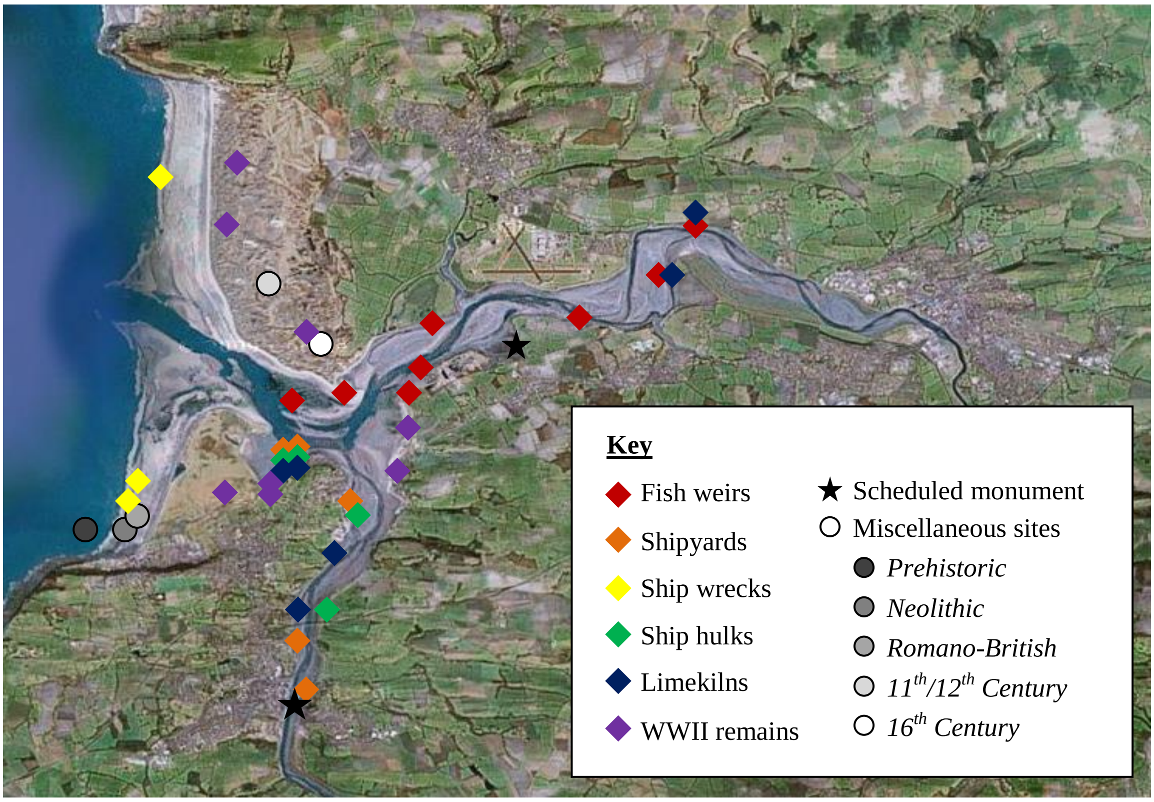

Figure 66. Sites of particular archaeological importance (using information from Preece, 2008)

Limekilns have been found near the sites of many of the weirs, as well as at other locations in the estuary (Preece, 2008). They were used to manufacture agricultural quicklime using limestone and culm (form of coal) that had been shipped across from South Wales.

The remains of several shipwrecked vessels (including at least two from the 1770s) can be found near the mouth of the estuary (Preece, 2008), most of which are periodically uncovered and recovered by the mobile sediments. The hulks of a variety of vessels including schooners, ketches, a barge and a trawler also remain on the estuary foreshore, most of which were abandoned after World War II. The area also contains remains from wartime exercises, as the estuary was used by the US army for assault training. These artefacts include vessel mock-ups, coastal defences, a radar bunker and weapons training facilities (Preece, 2008).

Structures from former shipyards are also found in the estuary (Preece, 2008). The Richmond Dry Dock in Appledore is a Grade II listed structure, disused slipways remain in the Skern, and the Brunswick Wharf in East-the-Water saw a recent resurgence in activity when the schooner *Kathleen and May* was restored, and remains moored, at the site. Built in 1900, the ship is the only UK-built wooden three-masted merchant schooner that has survived (National Register of Historic Vessels, 2009).

Shipbuilding

Shipbuilding is extremely important to the heritage of the area, although physical evidence remains for just a small proportion of the total number of shipyards that were found locally. At least 18 shipyards have operated on the estuary since the 18th century (Preece, 2008), which built the whole spectrum of vessel types including Men-of-War, East Indiamen, Post Office packets, and trawlers (Farr, 1976). The earliest record of a ship built in North Devon dates from 1242, when a half-built ship was found on Lundy (Farr, 1976). Ships are thought to have been built in Bideford as early as the 14th century, although the first formal record is of a 250 ton vessel built there in 1566 for an Exeter merchant (Rogers, 1947). The Torridge has always dominated the shipbuilding trade both within the estuary area and for North Devon as a whole. While the peak production years in the 1800s saw 2,000-3,000 ships built at yards on the Torridge, only 300-500 were built on the Taw and less than 200 were constructed in the rest of North Devon combined (Farr, 1976).

Shipbuilding began to decline from the mid-19th century. The trade ceased in the Taw in 1885, except for the construction of seven ships just after the First World War, and no ships were built elsewhere in North Devon after 1893 (Farr, 1976). Production declined to less than ten ships a year in the Torridge after 1900, although there was a brief revival in the trade between 1955 and 1974, when up to 23 ships were built in a year (Farr, 1976). The one remaining shipyard, at Appledore, has encountered difficulties in the past, going into receivership in 2003, but was recently awarded contracts by the Ministry of Defence.

Naval Battles

Throughout history, the ships built in Taw Torridge shipyards have been commandeered by the Crown in service of the realm. The Domesday Book mentions Barnstaple providing ships and men before the Norman conquest (Oppenheimer, 1968), and there are also records of a battle in the Taw Torridge itself, which saw off rebels from Ireland who, led by descendants of King Harold, came to challenge William the Conqueror (Fielder 1985).

Ships were also commandeered in 1302 for the Scottish campaigns and during the reigns of Henry IV, Henry V and Charles I (Oppenheimer, 1968). However, most deeply ingrained in the heritage of the area is the role of ships from the Taw Torridge during the defeat of the Spanish Armada in 1588. About six ships from Bideford appear to have been requested, of which three were actually sent to the battle (Oppenheimer, 1968). Local history often repeats an account of one of the Bideford ships, the *Victory*, encountering and defeating the Spanish vessel the *San Juan* in Bideford Bay and towing its prize into Appledore, after which the canon were removed and displayed in Bideford (Campbell, 1899; Fielder, 1985). Unfortunately, while the guns do appear to be Spanish and may even have been from the Armada, the actual historical evidence does not support this account of their capture (Campbell, 1899). While there appears to be little evidence of the role actually played by the local ships in the battle, both Bideford and Appledore were rewarded for their service by Elizabeth I, who granted both towns the status of Free Ports in perpetuity (Fielder, 1985).

Maritime Trade

In 1693, 64 local ships were trading with foreign ports and importing goods from North America, the West Indies and Ireland (Rogers, 1938). During the 18th century, Bideford was one of the principal trading towns in England, and between 1700 and 1750 Bideford imported more tobacco than any English port except for London (Rogers, 1947). Much of the tobacco trade was linked to colonies in North Carolina and Virginia, which local landowner Sir Richard Grenville had been instrumental in establishing. On his return from a voyage to North Carolina in 1585, Grenville brought back with him the first native American to be transported to the UK, a Wyngandtidoian Indian who was baptized in Bideford Church and buried there a year later (Fielder, 1985; Rogers, 1938). The trade with Maryland and Virginia stopped in 1760 and there was no trade at all with North America after 1774 (Rogers, 1938).

The American War of Independence also affected the fishing trade, which was already in decline by 1774 and subsequently never recovered (Oppenheimer, 1968). Ships had been exploiting the Newfoundland fisheries since 1626 (Rogers, 1947) and by 1699, 36 ships from Bideford and Barnstaple were engaged in the fishery, which represented nearly 20% of the entire fleet sailing from English ports (Oppenheimer, 1968; Rogers, 1938).

Local shipping was also used in the passenger trade. At least one ship from Barnstaple took part in the lucrative transport of pilgrims to the shrine of St James in Compostela in the 14th and 15th centuries (Oppenheimer, 1968), and the Bideford-built paddle steamer the *Torridge* did a large passenger trade with London and Bristol from 1835 to 1853 (Rogers, 1938)

Present day implications

The maritime heritage of the Taw Torridge is important locally, and fishing and shipbuilding both continue, albeit at a much reduced scale. Oral history projects have recently be commissioned, both in 2009 by Coastwise North Devon, a conservation NGO (Coastwise, 2010), and by local arts charity Appledore Arts in 2007 (Appledore Arts, 2010). The heritage is also important for tourism, with a large volume of promotional materials making reference to at least one aspect of the area's maritime history. The Free Port status also has management implications, as it has been interpreted, not necessarily correctly, as permitting unrestricted mooring within the estuary.

Psychological Wellbeing

Aesthetic appeal

The importance of the visual appeal of the unspoilt seascapes of the estuary mouth and wider coastline has been recognised by their designation as an Area of Outstanding Natural Beauty (Figure 67). Upstream areas of the estuary are more highly urbanised.

Aural Ambience

The estuary is not highly urbanised by national standards, but neither is it, as a whole, a haven of peace and quiet. There are roads within a few hundred meters of, and sometimes adjacent to, the shores of both the Taw and Torridge, as well as the towns of Barnstaple and Bideford and the smaller settlements along the south shore of the Taw. The presence of a large number of recreational users, particularly during the summer months, also creates disturbance.

Figure 67. The designated Area of Outstanding Natural Beauty ( ) along the coastline at the estuary mouth (from the North Devon AONB Partnership, 2009)

Inspiration

The best known contribution of the Taw Torridge to the Arts is as the inspiration for *Tarka the Otter*, the novel by Henry Williamson, which was first published in 1927 and tells a fictional story of a male otter living on the estuary. The maritime history of the area also makes a brief appearance in poetry, as the "men of Bideford" crewing for Sir Richard Grenville are immortalised in Alfred Lord Tennyson's work *The Revenge*, which details Grenville's death in battle with Spanish off the Azores in 1591.

More recently, the maritime history of the area inspired a dance project involving local community organisations and culminating in a performance in April 2010 in Clovelly (Fiona-Fraser-Smith, pers. comm.). Boatbuilding has also been a central theme of the annual Appledore Arts Festival. The natural history of the area has also inspired the festival, which had Wide River as its featured theme in 2007 and Coastlines in 2010 (Appledore Arts, 2010).

The cultural heritage and the environment of the area continue to inspire individual artists. The National Trust and Appledore Arts have created a new artist in residence programme at Bucks Mills Cabin in the historic fishing hamlet on the cliff near Clovelly, which was previously used as an artists' studio between 1913 and 1965 (National Trust, 2010). As well as being an inspiration, the shoreline has also been used as canvas on which to create art, and as a source of clays and other materials from which to create pigments (Peter Ward, 2010). Local schools have also worked with artists and art organisations on marine-themed art projects (Fiona-Fraser-Smith, pers. comm.).

I.6 Regulating Services

Physical wellbeing

Contaminant control

The management of waste entering the Taw Torridge is a serious issue, as has been referred to above in discussions of bathing and shellfish water quality. The Environment Agency is due to complete a shellfish water investigation in 2012, which will study the discharges affecting the Taw and Torridge rivers and make management recommendations (Northern Devon Coast and Countryside Service 2010a).

There are several separate waste issues affecting the estuary. Landfill sites were established on its banks, at sites including Barnstaple, Sticklepath, Bickington, Yelland and Northam Burrows (Environment Agency 2010a). These sites had all been all closed to landfill waste by 1994, but the sites pose a potential pollution risk should the estuary banks erode. Historically, there has been evidence of leachate at Bickington (TTEP, 1998), and the issue of environmental contamination is of particular concern for the Northam Burrows landfill, which is at a high risk of breaching due to sea level rise and the retreat of the Pebble Ridge (TTEP, 1998). Continued protection of the site has been recommended by the recent Shoreline Management Plan (NDSCAG, 2009). The Yelland Power Station site is potentially more of an environmental hazard as the waste includes asbestos, fuels and PCBs, although the risk of a breach is low, as the shoreline in that area is currently stable (TTEP, 1998).

The prevalence of marine litter has also been identified as a cause for concern in the 2010 Estuary Management Plan (Northern Devon Coast and Countryside Service, 2010a). Research from 2006/07 suggests that 70% of this waste is derived from fishing or shipping activities and beach visitors (Northern Devon Coast and Countryside Service, 2010a).

Other waste is also discharged directly into the estuary. A major source is the Ashford Sewerage Treatment Works, from which South West Water was, in 2010, licensed to discharge up to 74,999 tonnes of waste annually (Environment Agency, 2010c). Before discharge, the waste is given secondary and UV treatment and the nitrogen content is limited (Kevin Fear, pers. comm.). Also, the sewage treatment and discharge system in the estuary has been considerably restructured since the mid-1990s, when individual estuary outfalls were redirected through the Ashford plant (WS Atkins, 1992). A new offshore outfall at Cornborough was also completed in 2002 (Northern Devon Coast and Countryside Service, 2010b), to accommodate waste previously discharged through outfalls in Bideford and Yelland (Kevin Fear, pers. comm.) and a new works at Whitehall Cottage to replace crude discharge was completed in 2009 (Northern Devon Coast and Countryside Service, 2010b). There is also a sewage treatment works upstream in the Torridge at Great Torrington, which is located beyond the tidal limit of the estuary, but directly influences it.

Untreated sewage can also enter the estuary via the Combined Sewer Overflows (CSOs). Combined Sewers collect both surface water runoff and sewage in the same pipe system, and the outfalls form a safety value to prevent the runoff from heavy rainfall overwhelming the sewage system. There are a significant number of CSOs discharging into the estuary, although efforts are being made to monitor, improve or close as many as possible (Northern Devon Coast and Countryside Service, 2010b). South West Water recently installed an additional 35,000m^3 capacity storage tank at the Ashford treatment works to accommodate some of the storm overflow (Dean Davies, pers. comm.).

As well as human effluent, the sewage treatment works at Ashford and Great Torrington also discharge a wide range of industrial pollutants under licence on an annual basis, and the North Devon District Hosptial in Barnstaple has been licensed (in 2001 and 2003) to release iodine into the sewage system (Environment Agency, 2010b). The shipyard at Appledore has not recently been authorised to discharge waste into the estuary, although it has been granted licenses for atmospheric emissions (Environment Agency, 2010b).

Uncontrolled discharges also enter the estuary. Significant sewage pollution incidents occurred in 2007 at Bicklington and in 2008 at Fremington and Barnstaple, and a major water pollution incident, with potentially persistent and extensive effects, occurred in the Skern at Appledore in 2007, from an unidentified cause (Environment Agency, 2010b).

Agricultural runoff is also a serious issue in the estuary. The average annual rainfall in the Taw catchment is over 2,200mm near the source on Dartmoor and less than 940mm near the mouth, with a resulting runoff of 400-500mm per year (Haygarth et al., 2005). Animal effluent is a significant cause of water quality failure (Paul Carter, pers comm.), and Catchment Sensitive Farming (CSF) practices are encouraged in the area (Northern Devon Coast and Countryside Service, 2010b), although neither the Taw nor Torridge has been identified as a priority CSF area (DEFRA, 2009b). The sensitivity of the Taw to eutrophication has, however, been highlighted. It has been designated a Sensitive Area (Eutrophic) since 1998 under the Urban Waste Water Treatment Directive (DEFRA, 2008) and is also a Nitrate Vulnerable Zone under the Nitrates Directive, and so action is being taken to reduce the quantity of nitrates entering the water course from agricultural sources (DEFRA, 2010c).

Eutrophication is caused by increased nutrient loading and can result in oxygen depletion and toxic algal blooms. The factors contributing to eutrophication in the Taw Torridge have been assessed in detail by Maier et al. (2009). They conclude that the Taw Torridge is highly eutrophic during the summer months: between April and September (the main growth period), 12% of samples had high enough levels of chlorophyll-a to suggest a phytoplankton bloom, although these were obtained from a fortnightly or monthly sampling programme, so may underestimate the extent of the problem.

Maier et al (2009) also showed that 95% of the total inorganic nitrogen load entering the estuary is in the form of nitrate, 4.4% is ammonia and 0.6% is nitrite. The Ashford sewage treatment works contributes only 1-3% of the total nitrate load, suggesting the greater importance of diffuse sources in the nitrogen loading. Ashford does, however, contribute 74% of the ammonia loading, and the ammonia concentration local to this site appear to be a factor in inhibiting algal blooms. While this may appear potentially beneficial in reducing one of the consequences of eutrophication, the concentrations of ammonia observed were frequently high enough to be toxic to other species (Maier et al., 2009; Eddy, 2005).

The behaviour of waste and pollutants in the estuary depends on the physical, chemical and biological characteristics of the system, which may naturally dilute, disperse, transform, store or bury waste. The interaction of fresh and seawater is one important element of the system, and the Taw Torridge is generally well mixed (Soulsby et al. 1984; Sturley, 1990), although temporary salinity gradients can become established during periods of high river flow (Sturley, 1990), when the freshwater influence may also significantly reduce salinity near the mouth of the estuary (Maier et al., 2009). Conversely, there may be a strong influence of coastal waters near the tidal limit during periods of low freshwater flow (Maier et al., 2009).

Freshwater flushing time is one of most important filters affecting estuarine eutrophication (Maier et al. 2009). Flushing times have been estimated at 2-3days in the Taw and 1.5-2 days in the Torridge (Sturley, 1990), although these periods may vary considerably depending on tidal state and river flow (Sturley, 1990; Maier et al. 2009). Flood and ebb tides in the Taw are markedly unequal with progression towards springs, because low tide falls below the river level during periods of greater tidal range (Langhorne et al. 1985).

Inorganic nitrate is mainly supplied to the system as a result of runoff, but high freshwater flow flushes nutrients and algae out into coastal waters, reducing the tendency for algal blooms to develop within the estuary under these flow conditions (Maier et al., 2009). Intermediate flow regimes allow algal growth in the outer estuary, and low freshwater input reduces flushing to the extent that sufficient nutrients remain in the mid and upper estuary to support increased phytoplankton reproduction (Maier et al., 2009).

Eutrophication is also a factor of turbidity, as phytoplankton growth is limited when turbid water restricts light penetration (Maier et al, 2009; Alpine and Cloern, 1988). Suspended sediments also play a role in contaminant transport, particularly fine-grained sediments to which particulate nutrients, toxic metals and pathogens may become attached (Deasy et al., 2009). When the rivers are in spate, they transport large quantities of fine sediment from the catchment areas (Langhorne et al. 1985), and recorded concentrations of suspended silt and fine clay in the Taw have ranged from 25-185mg.l^{-1} (Soulsby et al., 1984). The Taw is also characterised by high concentrations of suspended sand, transported by the strong rectilinear tidal currents (Rose et al 2001; Thorne and Hardcastle, 1998). The flood tide is strongly dominant, and suspended sediment concentrations in excess of 800mg.l^{-1} have been recorded during periods of peak flow (Soulsby et al., 1984).

Contaminants bound to suspended sediment particles may be deposited on the estuary banks and bed, and the sediments in freshwater wetland marshes and accreting saltmarsh areas have been shown to be sinks for nutrients and pollutants (DeLaune et al., 1986; Andrews et al., 2008). The burial of contaminants in sediments is not necessarily a permanent solution, however, as they may be remobilised by, for example, bioturbation of the sediments by burrowing polycheates (Josefsson et al., 2010). The potential for contaminant resuspension is an issue within the Taw Torridge, as there is evidence of industrial contamination near Appledore and Bideford, where high concentrations of PCBs have been found in the sediments (TTEP, 1998).

The biota also play an important role in the removal of waste and contaminants. Coastal wetland vegetation has been shown to remove up to 85% of nitrates and 76% of phosphates from secondary-treated wastewater (Breaux et al., 1995), and brown algae are highly effective at removing metals such as copper and zinc from the water column (Davis et al., 2003). Filter-feeders such as bivalves and polycheate worms also extract contaminants including bacteria, metals and halogenated hydrocarbons from the surrounding water (Stabili et al., 2006; Roslev et al., 2009; Clark, 1992). Micro-organisms including fungi, mould and bacteria have also been shown to effectively remove metals and other contaminants including faecal pathogens and oil (Jong and Parry, 2003; Salehizadeh and Shojaosadati, 2001; Vieira and Volesky, 2000).

Contaminants taken up by biota may simply accumulate within the organisms' tissue, and so may become re-available on decomposition or be transmitted up the food chain. Also, this bioaccumulation may have toxic effects on the organism concerned, and this may be a particular issue for estuarine species, which are potentially already more stressed than fully marine or terrestrial species as a result of the daily variation the environmental conditions such as temperature and salinity (Eddy, 2005). The toxicity implications of bioaccumulation may also affect species at higher trophic levels, as evidenced by the human health risks from consumption of contaminated shellfish.

Total removal of contaminants from the system requires transformation to harmless substances, a process in which bacteria play an important role in, for example, denitrification of organic waste (Dodla et al., 2008) and dechlorination of halogenated pollutants (Bunge et al., 2003).

The role of specific elements within the estuarine system in the degradation of particular wastes and pollutants is difficult to quantify, not least because mechanisms for the uptake and transformation of contaminants are not fully understood (Edgar et al., 2006). The potential for contaminant control is, however, a function of the area of habitat, species present and other pressures on the system, as well as of the wider environmental variables such as salinity and sediment type. There is a lack of detailed ecological data available for the Taw Torridge that would permit comprehensive assessment of its capacity for contaminant control.

Some information to characterise the habitats and species within the Taw Torridge is, however, available. Saltmarsh habitats and fine grained sediments appear to play a particular role in contaminant control, and data held by the Devon Biodiversity Records Centre suggest that there is approximately 250ha of saltmarsh and 520ha of mudflat within the Taw Torridge estuary (Figure 68). The rest of the estuary bed is generally sandy, particularly in the Taw, with somewhat finer sediments in the Torridge (Pethick, 2007).

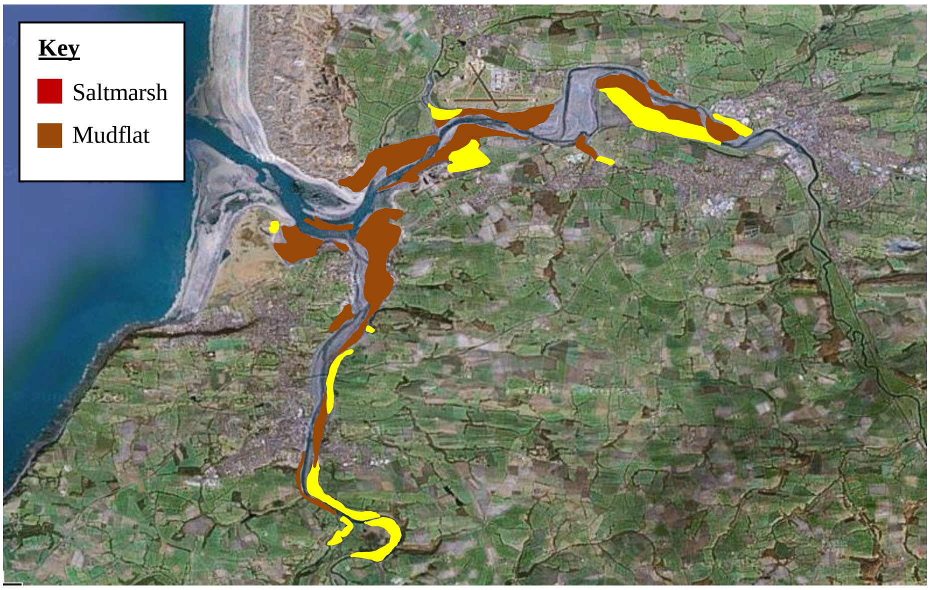

Figure 68. The main saltmarsh and mudflat habitats within the Taw Torridge estuary (adapted from unpublished data supplied by the Devon Biodiversity Records Centre)

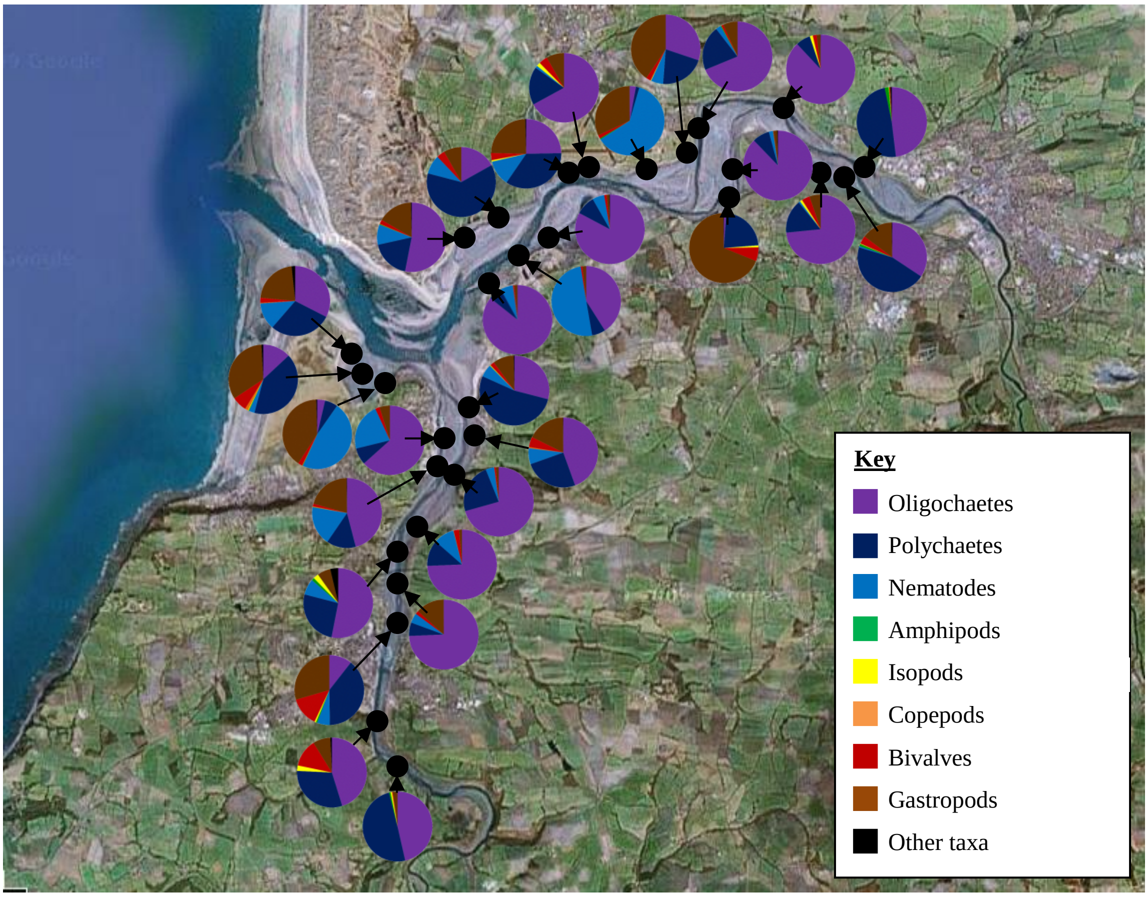

Figure 69. Benthic infauna in estuary sediments (Environment Agency, unpublished data)

Ecological surveys were carried out by Little (1989) to characterise the plant and animals communities within the estuary, but these are not current. More recently, the Environment Agency has carried out a survey of benthic infauna at 30 stations around the estuary in 2008, which show a general dominance of oligochaete and polychaete worms with gastropods occasionally dominating at certain sites (Figure 69).

Air quality regulation

The atmosphere carries a range of particulates and pollutants including ozone, methane, sulphur dioxide and nitrous oxide, which have implications for human health and the effective functioning of the wider environment (House and Brokovin, 2005). Seawater is a sink for many these compounds, and so plays a role in the provision of clean air. However, the interactions between the atmosphere and the ocean are very complex; seawater can also be a source of gases and particulates, and its local role as a sink is affected by a number of factors such as thermal stratification (Kang et al., 2010), the composition of surface microlayer (Chester, 1990), the wider chemical composition of seawater and the other inputs to the water body (Theodosi et al, 2010).

There is insufficient data on atmosphere-estuary interactions to permit any attempt to quantify the air quality regulation service provided by the Taw Torridge.

Disturbance prevention

Flood control

There is a significant flood risk to settlements surrounding the Taw Torridge estuary, many of which have substantial areas classified within the highest risk category (Zone 3 in the Government's Planning Policy Statement 25) (Environment Agency, 2011). The greatest number of properties at risk of flooding are, not surprisingly, in the largest population centres: 1,900 properties are at risk in Barnstaple, 800 in Bideford and 500 in Braunton (Environment Agency, 2009b). Floods also affect infrastructure including schools, hospitals, roads, railways, and electricity substations, although no sewage or water treatment plants are thought to be at risk (Environment Agency, 2009b).

The most recent severe flood prior to 2010 occurred in 2000, and affected some 200 properties, about half of which were in Barnstaple (Environment Agency, 2008). Bideford has also seen serious floods affecting more than 100 properties in 1993 and 1984 (Environment Agency, 2008; NDC and TDC, 2009b). Braunton, Fremington, Appledore and Instow also have a long history of flooding, for some properties as recently as 2004. Some of the worst affected areas are at the estuary's tidal limts: the Torridge at Weare Giffard has flooded almost 100 times in 30 years (NDC and TDC, 2009b), while flood waters from the Taw reached a height of nearly 7m at Bishop's Tawton during the 2000 flood event (NDC & TDC, 2009a).

Fluvial flooding is the most common source, although the major floods affecting the area resulted from a combination of fluvial, tidal and surface water overflow. Sewer and groundwater flooding do occur in the area, but to a much lesser extent (Environment Agency, 2008).

In response to major flood events, defences have been constructed to protect the towns, which have reduced the frequency of flood damage. Significant works took place in Barnstaple following a major flood in 1981, and the defences can contain flood waters of up to 8m in height in some parts of the town (NDC and TDC, 2009a). New defences were also completed in Bideford in 2005, before which the quay tended to flood two or three times a year, although generally without damage to property (NDC and TDC, 2009b). As a result of these and other recent works as well as historic land enclosures and defences constructed to protect the former railway line, there is at least some degree of flood protection along almost the entire length of the estuary banks (Figure 70).

Figure 70. The extent of manmade flood defences along the banks of the Taw Torridge (using information from NDC & TDC. 2009a,b; TTEP, 1998)

It has been estimated that the current level of flood defence could reduce the average annual economic impact of flood damage by £33million (Environment Agency, 2008). However, flooding is predicted to worsen in the future due principally to rising sea level, which, when combined with population growth, suggests that the number of properties at risk by 2100 could increase by 50% for both the Taw and Torridge (Environment Agency, 2008). The economic damages from flooding across North Devon could be as high as £950 million by 2100, with Barnstaple and Bideford the worst affected areas (Environment Agency, 2008).

In attempting to mitigate future flood risks, the Environment Agency (2008) has proposed different strategies for different areas of the estuary. There is particular concern for Braunton, as flood risk threatens 22% of the population and there is a high risk to critical infrastructure, and so the preferred policy is to take action to reduce the flood risk. It is also proposed that improvements should be made to the defences around other population centres on both the Taw and the Torridge (including Barnstaple, Fremington, Yelland, Bideford, Appledore and Instow).

However, a policy of managed realignment has also been proposed for other parts of the estuary, which would allow previously enclosed and defended areas to revert to intertidal zones (Environment Agency, 2008; Halcrow Group Ltd, 2009). A particular focus for managed realignment is the area around Horsey Island, on the north shore of the Taw to the east of Braunton Burrows, near its confluence with the Torridge. This area was reclaimed in two phases during the first half of the nineteenth century, as it was deemed to be more valuable as agricultural land (Manning, 2007).

Were managed realignment to take place, the flood protection service provided by the ecosystem in would become more apparent. At present, this is difficult to gauge given the current level of manmade coastal defence. The benefits that could be provided by the ecosystem have been recognised in the arguments for managed realignment: restoring natural floodplains and increasing the water storage potential of the estuary could potentially reduce the flood risk in other areas (Environment Agency, 2008). Saltmarshes also mitigate the effects of flooding, as they can absorb large quantities of water. The presence of wide areas of saltmarsh substantially reduce sea defence requirements (King and Lester, 1995).

Erosion control

Coastal erosion has also been highlighted in shoreline management plans, and has led to the construction of coastal defences. In particular, significant erosion is occurring along the Bideford Bay coastline. Only minimal impact is predicted along Saunton Sands to the north, but a considerable loss of area from Northam Burrows and Westward Ho! to the south of the estuary is predicted within the next 100 years (Halcrow Group Ltd, 2009), which has particular implications for the town at Westward Ho! and also for the disused landfill site on Northam Burrows.

This southern coastline is characterised by a pebble ridge, which has retreated by at least 150m in the last 150 years (May, 2003). It is losing sediment at a rate of up to 5,000m^3 per year, although this decline appears to be slowing as the ridge realigns (Pethick, 2007). Programmes of beach nourishment have been instigated since the 1980s, and rock armouring has been constructed to protect the ridge (May, 2003). Intervention is required to maintain these defences particularly after storms (Pethick, 2007) such as the gales in March 2008, which caused considerable damage to the ridge (TTEF, 2008). The pebble ridge may be a relatively recent geological feature that may have been created in the sixteenth and seventeenth centuries following landslips, and the erosion of this short-lived feature is to be expected as the system returns to equilibrium (Pethick, 2007).

Within the estuary itself, the neck of the sand spit at Crow Point is subject to erosion, and has breached in the past, so it is currently protected by manmade defences (Halcrow Group Ltd, 1998). It has been suggested that the spit is not actually a natural feature of the estuary, but arose after the construction of a fish weir in the early nineteenth century, and its erosion is a consequence of the removal of the weir (Pethick, 2007). Erosion is not of major concern elsewhere within estuary and there is net accretion occurring within the Taw, to the extent that channels are silting up (TTEP, 1998).

The presence of such significant flood defences along the estuary coastline again make it difficult to quantify the contribution of the ecosystem to erosion control. However, as with flood defence, saltmarshes are known to play an important role as they reduce flow speeds (Leonard and Croft, 2006) and dissipate wave energy (Möller et al., 2001).

Climate regulation

Marine biota and seawater chemistry also contribute to climate regulation, through the ocean-atmosphere exchange of carbon dioxide (CO_2). This exchange is affected by physical and chemical factors including wind-induced mixing of the water column, temperature and salinity, and also by biological controls such as the level of primary production, which can have a very strong influence on the air-sea flux (Kaltin and Anderson, 2005). The relative influence of the different parameters can vary spatially, with biologically activity driving the flux in inner estuary areas and wind speeds exerting greater influence offshore (Álvarez et al., 1999). The biological drivers within the system include fixation of dissolved CO_2 by phytoplankton and the production of calcium carbonate (Álvarez et al 1999) as well as food web exchanges that control the transportation and transformation of organic carbon (Legendre and Rivkin 2002).

The climate regulation service provided by the Taw Torridge cannot be quantified as there is insufficient data available. Also, it is questionable whether the contribution of an area as small as the Taw Torridge can be considered in isolation from the wider coastal area.

I.7 Conclusions

The benefits people gain from the cultural services provided by the Taw Torridge are particularly significant; the estuary is very important for recreation and tourism, and the area has a strong cultural heritage (Table 44). Watersports and shoreline recreational activities are extremely popular, the presence of waders and wildfowl attracts birdwatchers, and recreational anglers target salmon and sea trout as well as marine fish. Commercial fishers and shellfish harvesters do work within the estuary but only on a small-scale, although the estuary is used by marine species that are important to the commercial inshore fisheries based in Bideford and Appledore. There is little commercial shipping within the estuary, but it is a unique site for military amphibious craft training. The area surrounding the estuary has a high risk of tidal and fluvial flooding, which is expected to worsen over time. Poor water quality is another major policy issue, as sewage and agricultural runoff regularly contaminate the estuary, causing bathing and shellfish waters to be downgraded.

Table 44. A summary of the relative importance of the ecosystem services provided by the Taw Torridge Importance (in terms of policy drivers and/or number of people affected)**:** *** high, ** moderate, * low

Type of value	Service category	Service type	Benefit	Importance
Direct Use (Consumptive)	Production	Food	Shellfisheries (shore based)	*
			Shellfisheries (subtidal)	**
			Eels/salmonids	*
			Marine fish	**
			Marine plants	*
		Raw materials	Bait	*
			Exported spat/broodstock	*
Direct Use (Non-Consumptive)	Carrier	Provision of space	Commercial transport	*
			Military operations	***
			Mooring	*
			Cables and pipelines	*
			Dredge disposal	*
			Waste disposal	*
	Cultural	Recreation & tourism	Nature watching	***
			Sea angling	***
			Wildfowling	*
			Watersports	***
			Swimming	**
			Coastal margin activities	***
		Cognitive development	Education	**
			Research	*
		Heritage & identity	Archaeology	**
			Cultural heritage	***
Non-Use		Existence		**
		Bequest		**
Indirect Use		Psychological wellbeing	Aesthetic appeal	**
			Aural ambience	*
			Inspiration	*
	Regulating	Physical wellbeing	Contaminant control	***
			Air quality regulation	*
		Disturbance prevention	Flood control	***
			Erosion control	*
			Climate/weather regulation	*
Option	Encompasses all categories			**

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II. Survey Instruments: Contingent valuation and Analytic Hierarchy Process

Survey of Preferences for Tidal Power Generation

Instructions to interviewers:

1. Please read out only the text in *italics* and the questions, which are numbered and shown in **bold** type. All questions should be completed.
2. Questions 1,2 and 17 do not require a response, but should be filled in by you. These questions for which no response is required are in boxes, and the question text is in normal type.
3. Further instructions at particular points in the questionnaire are shown in CAPITAL LETTERS.

INTRODUCTION

Hello, I'm conducting a survey for the University of Bath and the Plymouth Marine Laboratory about using tidal power to generate electricity in a UK estuary. The questions in the survey aim to find out your attitudes and opinions, and there are no right or wrong answers. The survey is being carried out purely for research purposes. It is entirely confidential, and your survey answers will be anonymous.

The questions take about 15-20 minutes to complete – would you be able to help me with this?

1. Start time:............................

This research is concerned with the possible use of tidal flows in the Taw Torridge estuary to generate electricity.

2. Is the interview site within 10 miles of the tidal limit of the Taw or the Torridge rivers?

TICK 'NO' FOR WELLINGTON; 'YES' OTHERWISE

Yes	☐	GO TO PART II
No	☐	GO TO PART I

PART I. THE TAW TORRIDGE ESTUARY

SHOW CARD A. *The Taw Torridge estuary is in this part of North Devon.* USE PEN TO INDICATE LOCATION OF THE ESTUARY BETWEEN BARNSTAPLE AND BIDEFORD (THE RED SQUARE ON THE UPPER MAP).

This is a more detailed map INDICATE THE LOWER MAP *showing the area within 10 miles of the tidal limit of the estuary.* TRACE AREA OUTLINED IN RED WITH PEN.

3. Have you ever visited this area?

Yes	☐	GO TO Q4
No	☐	GO TO PART II

4. How often have you visited this area during the last 5 years? DO NOT READ OUT THE OPTIONS: TICK THE BOX THAT REFLECTS THE RESPONDENT'S ANSWER

At least once per month	☐	Less than once per year	☐
6-11 times per year	☐	Once	☐
2-5 times per year	☐	Not within the last 5 years	☐
Once per year	☐	Can't remember	☐

PART II. ENERGY ISSUES

SHOW CARD B. *The UK Government is looking for alternative ways to produce electricity that do not involve burning fossil fuels: coal, oil and gas. There are two main reasons for this:*

a. Burning fossil fuels produces carbon dioxide, and the Government (along with other Governments and many scientists) believes that carbon dioxide is linked to climate change - a term used to describe increasing global temperature and changing weather patterns.

b. The Government is looking to ensure that the country can maintain a reliable electricity supply into the future, should coal, oil and gas run out or otherwise become difficult to obtain.

5. Looking at the statements about energy issues on this card INDICATE ON CARD B **, to what extent do you agree or disagree with them?**

	Strongly agree	**Agree**	**Neither agree nor disagree**	**Disagree**	**Strongly disagree**	**Don't know**
Climate change is a real problem now	☐	☐	☐	☐	☐	☐
Climate change will be a real problem in the future	☐	☐	☐	☐	☐	☐
Burning fossil fuels (coal, oil and gas) is a major cause of climate change	☐	☐	☐	☐	☐	☐
The UK should rely less on imported fuel and produce more energy from sources within its own borders, even if this means electricity bills go up	☐	☐	☐	☐	☐	☐

SHOW CARD C. *One way to reduce fossil fuel use is to generate electricity using sources of energy such as wind, solar, hydroelectric (from rivers), wave energy, tidal current turbines and tidal barrages.* INDICATE EACH RENEWABLE ENERGY PICTURE ON CARD C.

6. On this scale INDICATE ON CARD C, **how well informed do you think you are about using tidal barrages as a source of renewable energy for generating electricity?**

Very well informed	**Well informed**	**Quite well informed**	**Not very well informed**	**Not at all informed**	**Don't know**
☐	☐	☐	☐	☐	☐

7. Do you generate any of your own household electricity, for example with solar panels or a wind turbine?

Yes	☐	No	☐

PART III. BARRAGES AND COASTAL MUDFLATS

SHOW CARD D*. The Government is looking at various ways to increase the use of renewable energy to generate electricity because it has set a target to reduce fossil fuel use by 2020. One option which could help to meet this target is building a barrage in the Taw Torridge estuary to generate electricity from tidal flows.*

Remember that this is a research exercise. It is based on the kind of decisions about energy that are being made but does not reflect an actual plan that is being considered at the moment.

A tidal barrage would look something like this. INDICATE BARRAGE PICTURE ON CARD D.

Tidal barrages are not solid dams and do not create lakes upstream – the tide continues to go in and out every day and it is these flows of water that generate electricity. However, the tide upstream of the barrage would not go out as far as it did before. Therefore, construction of a barrage would mean that some area of coastal mudflat would be lost, as it would end up permanently underwater.

Mudflats are important feeding grounds for some birds. INDICATE MUDFLAT PICTURES ON CARD D. *Reducing the area of mudflat would make bird feeding grounds smaller, so the number of birds in the Taw Torridge could decline if a barrage were built. Some of these birds would find new feeding grounds in other estuaries, but other birds may not: research has shown that the loss of a particular feeding ground can cause the death of birds such as Redshank.*

There are different options for the design of tidal barrages, depending on the turbine type, the way in which they are operated and exact location within a particular estuary. Imagine now that three alternative barrage designs are being considered for the Taw Torridge estuary: Barrage A, Barrage B and Barrage C. They all produce the same amount of electricity but the amount of mudflat that would be lost is different for each barrage. The largest area of mudflat would be lost with Barrage A and the least with Barrage C. The amount of mudflat lost with Barrage B is halfway between. The cost of each barrage would also be different and I'm going to ask about how much you might be willing to pay through your electricity bills for Barrage B or C.

SHOW CARD E. *First, I would like to ask you about Barrage B compared to Barrage A.*

> ***Barrage A*** INDICATE ON CARD E *would result in the loss of 210 hectares of coastal mudflat, which is 42% (nearly half) of the total coastal mudflat in the estuary. One hectare (2.5 acres) is about the size of a professional football pitch.*
>
> ***Barrage B*** INDICATE ON CARD E *would result in the loss of 140 hectares, which is 28% (just over one quarter) of the total area of mudflat.*
>
> *Assume that **Barrage A** would produce electricity at the same cost as now, and so would not result in any increase in bills for electricity customers.*
>
> *However, **Barrage B** would be more expensive to build and operate than Barrage A, so your electricity bills would be higher with Barrage B.*

8. The loss of coastal mudflat with Barrage B would be 70 hectares <u>less</u> than with Barrage A. If Barrage B cost you 50p per year extra on your electricity bill, would you be <u>in favour</u> of Barrage B, or <u>not in favour</u> of Barrage B?

Yes, in favour of Barrage B	☐	GO TO Q11
No, not in favour of Barrage B	☐	GO TO Q9

9. Is there any amount that you would be prepared to pay to have Barrage B instead of Barrage A?

No	☐		GO TO Q10
Yes	☐	IF YES, ASK: **What would be the most you would pay per year? ......**	GO TO Q13
Don't know	☐		GO TO Q10

10. SHOW CARD F **How far do you agree or disagree with the following statements?**

NOTE: THERE ARE TWO VERSIONS OF CARD F. SHOW CARD F2 (WITH THE FIRST STATEMENT) TO RESPONDENTS IN WELLINGTON. SHOW CARD F1 (WITHOUT IT) OTHERWISE.

	Strongly agree	**Agree**	**Neither agree nor disagree**	**Disagree**	**Strongly disagree**	**Don't know**
I do not want to pay for reducing coastal mudflat loss in the Taw Torridge estuary as I don't go there	☐	☐	☐	☐	☐	☐
A tidal barrage should not be built in the Taw Torridge estuary under any circumstances	☐	☐	☐	☐	☐	☐
I object to paying higher electricity bills to pay for any tidal barrage	☐	☐	☐	☐	☐	☐
I object to paying higher electricity bills to support any renewable energy development	☐	☐	☐	☐	☐	☐
I cannot afford to pay any more on my electricity bill, however worthy the cause	☐	☐	☐	☐	☐	☐

GO TO Q15

11. I'd like to find out now whether you would be in favour of Barrage B if it cost more than 50p extra on your electricity bill each year compared to Barrage A. SHOW CARD G. **Looking at the amounts listed on this card**, **what is the most you would pay per year to secure Barrage B instead of Barrage A?**

Please think carefully about how much you can really afford, and where the additional money would come from, bearing in mind the other things you have to spend your money on.

75p	☐	£3.50	☐	£8	☐	£18	☐	£45	☐	£100	☐
£1	☐	£4	☐	£9	☐	£20	☐	£50	☐	£125	☐
£1.50	☐	£4.50	☐	£10	☐	£25	☐	£60	☐	£150	☐
£2	☐	£5	☐	£12	☐	£30	☐	£70	☐	£175	☐
£2.50	☐	£6	☐	£14	☐	£35	☐	£80	☐	£200	☐
£3	☐	£7	☐	£16	☐	£40	☐	£90	☐	More	☐

FOR RESPONDENTS CHOOSING BETWEEN 75p AND £200 (INCLUSIVE) GO TO Q13

FOR RESPONDENTS CHOOSING 'MORE' THAN £200 in Q11 GO TO Q12

12. What would be the most you would pay per year? £......................

Now, this time, I would like to ask you about Barrage C compared to Barrage A. SHOW CARD H. INDICATE 'BARRAGE C' BOX. *Barrage C would result in the loss of 70 hectares of coastal mudflat, which is 14% of the total area of mudflat in the estuary.* INDICATE 'BARRAGE A' BOX. *Barrage A would still result in the loss of 210 hectares of coastal mudflat (42% of the total area of mudflat in the estuary). Both barrages still produce the same amount of electricity. Barrage C would be more expensive to build and operate than Barrage A, so your electricity bills would be higher with Barrage C.*

13. The loss of coastal mudflat with Barrage C would be 140 hectares <u>less</u> than with Barrage A. Looking at the amounts listed on this card SHOW CARD I, **what is the most you would pay per year to have Barrage C instead of Barrage A? To remind you, in the previous exercise you said that the most you would pay to save 70 hectares of coastal mudflat is** STATE AMOUNT IN Q9/Q11/Q12 AS APPROPRIATE**.**

Again, bear in mind the other demands on your household budget, and try to give the most realistic answer.

10p	☐	£2	☐	£5	☐	£12	☐	£30	☐	£60	☐	£125	☐
25p	☐	£2.50	☐	£6	☐	£14	☐	£35	☐	£70	☐	£150	☐
50p	☐	£3	☐	£7	☐	£16	☐	£40	☐	£80	☐	£175	☐
75p	☐	£3.50	☐	£8	☐	£18	☐	£45	☐	£90	☐	£200	☐
£1	☐	£4	☐	£9	☐	£20	☐	£50	☐	£100	☐	More	☐
£1.50	☐	£4.50	☐	£10	☐	£25	☐						

FOR RESPONDENTS CHOOSING BETWEEN 10p AND £200 (INCLUSIVE) GO TO Q15

FOR RESPONDENTS CHOOSING 'MORE' THAN £200 in Q13 GO TO Q14

14. What would be the most you would pay per year? £......................

15. SHOW CARD J **How far do you agree or disagree with the following statements?**

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree	Don't know
Building more wind farms would be better than building tidal barrages, even if this costs me more money	☐	☐	☐	☐	☐	☐
Building more nuclear power stations would be better than building tidal barrages, even if this is more costly to me	☐	☐	☐	☐	☐	☐

PART IV. OTHER BARRAGE CHARACTERISTICS

SHOW CARD K *We have just discussed two particular characteristics of tidal barrages, which are:* INDICATE EACH AS YOU READ THE TEXT.

Loss of coastal mudflat

The area of coastal mudflat will be reduced if a tidal barrage is built.

Additional cost of electricity each year

The design of the barrage will affect the cost of each unit of electricity produced, which could result in an increase in bills for electricity customers.

The design and location of a barrage can also bring some benefits to the area. Two of these benefits are: INDICATE EACH AS YOU READ THE TEXT.

The number of homes with additional flood protection

Tidal barrages can provide additional flood protection to homes and other buildings in the area upstream of the barrage.

Additional time available for watersports

The time available for recreational activities like sailing, kayaking and other watersports will increase because the tide upstream of the barrage will not go out as far as it would normally, and so there will be deeper water in this area of the estuary for a longer period each day.

I'd like to ask you now about how important these four barrage characteristics are to you. I will show you the different characteristics two at a time. Think first about which of the two characteristics shown is more important to you. Then decide how much more important it is than the other characteristic shown, on a scale of 1 – 9: The more important the characteristic is compared to the other one, the higher the number should be.

SHOW CARD L, AND WORK THROUGH THE FIRST COMPARISON AS AN EXAMPLE :

Example:

Number of homes with additional flood protection

Additional time available for watersports

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Very much more important — Equal importance — Very much more important

If the number of homes with additional flood protection is very much more important to you than the additional time available for watersports, you should rate number of homes with flood protection as '9': ON CARD K, POINT TO '9' ON THE LEFT HAND SCALE, AS SHOWN BELOW.

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

If, on the other hand, the additional time available for watersports is moderately more important to you than the number of homes with additional flood protection, you should rate watersports as '5': ON CARD K, POINT TO '5' ON THE RIGHT HAND SCALE, AS SHOWN BELOW.

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

If the number of homes with additional flood protection and the additional time available for watersports are of equal importance, you should rate them as '1': ON CARD K, POINT TO '1' IN THE CENTRE OF THE SCALE, AS SHOWN BELOW.

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Do you understand the task?

16. On a scale of 1 – 9, please rate each of the three pairs shown on the card according to which characteristic would be more important to you in choosing between different barrage options.

The respondent gave the following ratings:

Flood protection								v				Watersports gain				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Flood protection								v				Coastal mudflat loss				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Flood protection								v				Cost				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

SHOW CARD M. *Please continue for these last three pairs as well.*

Watersports gain								v				Coastal mudflat loss				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Watersports gain								v				Cost				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Coastal mudflat loss								v				Cost				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

PART V. BACKGROUND INFORMATION

In this final section, I would like to collect some more information about you. The questions are not meant to be intrusive, but factors like the size of your household affect the decisions you make. Remember that the survey is anonymous – we will not be able to identify you.

17. Gender: a. ☐ Male b. ☐ Female

18. What is your postcode: ______________

SHOW CARD N (WHICH LISTS QS18-24)

19. Which age group are you in?

a. ☐18-24 b. ☐ 25-34 c. ☐ 35-44 d. ☐ 45-54 e. ☐ 55-64 f. ☐ Above 64

20. Including yourself, how many people in each of the following age groups are currently part of your household year round?

a. Under 18yrs .... b. 18-64yrs .... c. 65 and over ....

21. Are you: a. ☐ employed b. ☐ self-employed c. ☐ retired d. ☐ looking after a home full-time
e. ☐ a student f. ☐ temporarily unemployed g. ☐ unable to work due to sickness or disability

22. What is your approximate total annual household income before tax:

a. ☐ Less than £5,000
b. ☐ £5,001 to £15,000
c. ☐ £15,001 to £25,000
d. ☐ £25,001 to £35,000
e. ☐ £35,001 to £45,000
f. ☐ £45,001 to £55,000
g. ☐ £55,001 to £65,000
h. ☐ £65,001 to £75,000
i. ☐ £75,001 to £85,000
j. ☐ £85,001 to £100,000
k. ☐ More than £100,000
l. ☐ don't know/declined to answer

23. Which of the following qualifications do you have? TICK ALL THAT APPLY.

a. ☐ GCSE or equivalent
b. ☐ A level/AS level or equivalent
c. ☐ Diploma/technical qualification
d. ☐ College/University degree (first or postgraduate)
e. ☐ Professional qualification
f. ☐ No qualifications

24. On average, how much has your household been paying each month for electricity bills in the past 12 months? *(Please give your approximate average monthly total throughout the year)*

a. ☐ £0 – £20
b. ☐ £21 – £30
c. ☐ £31 – £40
d.☐ £41 – £50
e.☐ £51 – £60
f.☐ £61 – £70
g. ☐ £71 – £80
h. ☐ £81 – £90
i. ☐ £91 – £100
j. ☐ Above £100
k. ☐ Unsure

INTERVIEWER INDICATE WHETHER THIS AMOUNT IS:

a. ☐ electricity bill total (actual or estimate)
b. ☐ combined gas & electricity bill total (actual or estimate)
c. ☐ estimate of electricity cost from combined bill

25. Are you a member of any national or local nature conservation organisation (such as the RSPB, a Wildlife Trust, Greenpeace, etc, but excluding the National Trust)?

a. ☐ Yes b. ☐ No

26. On this card is a list of activities that some people enjoy doing at the by the sea or on rivers. Please could you tell me how often you do any of these in the UK, using the scale shown?

	At least once per week	**At least once per month**	**At least once per year**	**Less than once per year**	**Never**
Watersports (e.g. sailing, surfing, kayaking, outdoor swimming)	☐	☐	☐	☐	☐
Walking/cycling on coast or river paths	☐	☐	☐	☐	☐
Bird watching	☐	☐	☐	☐	☐
Wildfowling (hunting duck & geese)	☐	☐	☐	☐	☐
Recreational angling/crabbing	☐	☐	☐	☐	☐

PART VI. TO BE COMPLETED BY THE INTERVIEWER

27. Survey end time ....

28. Do you think the respondent understood the valuation exercise?

1. ☐ Yes 2. ☐ No

29. On a scale of 1 (very easy) to 5 (very difficult), how difficult do you think it was for the respondent to complete the valuation exercise?

Very easy				**Very difficult**
1	2	3	4	5
☐	☐	☐	☐	☐

30. On a scale of 1 (not at all annoyed) to 5 (very annoyed), how annoyed do you think the respondent was by the survey?

Not at all annoyed				**Very annoyed**
1	2	3	4	5
☐	☐	☐	☐	☐

31. In the event that the respondent stopped the survey, do you think that the respondent:

☐ Did not understand the survey

☐ Was annoyed by the survey

☐ Was annoyed by the length of the survey

☐ Other...

32. General comments on the interview (if any):

....

....

....

....

....

....

....

....

33. Survey type: In house ☐ Door step ☐ Street ☐

34. Survey site: ....

35. Weather: ....

36. Interviewer: ....

37. Date: ....

PART I (A)

The location of the Taw Torridge Estuary

The area with 10 miles of the estuary tidal limits

PART II **B**

The UK Government is looking for alternative ways to produce electricity that do not involve burning fossil fuels (coal, oil and gas). There are two main reasons for this:

1) Burning fossil fuels produces carbon dioxide, and the Government (along with other Governments and many scientists) believes that carbon dioxide is linked to climate change - a term used to describe increasing global temperature and changing weather patterns.
2) The Government is looking to ensure that the country can maintain a reliable electricity supply into the future, should coal, oil and gas run out or otherwise become difficult to obtain.

Looking at the statements about energy issues on this card, to what extent do you agree or disagree with them?

	Strongly agree	**Agree**	**Neither agree nor disagree**	**Disagree**	**Strongly disagree**
Climate change is a real problem now	☐	☐	☐	☐	☐
Climate change will be a real problem in the future	☐	☐	☐	☐	☐
Burning fossil fuels (coal, oil and gas) is a major cause of climate change	☐	☐	☐	☐	☐
The UK should rely less on imported fuel and produce more energy from sources within its own borders, even if this means electricity bills go up	☐	☐	☐	☐	☐

C

One way to reduce fossil fuel use is to generate electricity using sources of energy such as:


wind


solar


hydroelectric (from rivers)


wave


tidal current turbine


tidal barrage

Using the scale below, how well informed do you think you are about using tidal barrages for generating renewable electricity?

- Very well informed
- Well informed
- Quite well informed
- Not very well informed
- Not at all informed

D

The Government is looking at various ways to increase the use of renewable energy to generate electricity because it has set a target to reduce fossil fuel use by 2020. One option which could help to meet this target is building a barrage in the Taw Torridge estuary to generate electricity from tidal flows.

Remember that this is a research exercise. It is based on the kind of decisions about energy that are being made but does not reflect an actual plan that is being considered at the moment.

A tidal barrage would look something like this:

Tidal barrages are not solid dams and do not create lakes upstream – the tide continues to go in and out every day and it is these flows of water that generate electricity. However, the tide upstream of the barrage would not go out as far as it did before. Therefore, construction of the barrage would mean that some area of coastal mudflat would be lost, as it would end up permanently underwater.

Mudflats are important feeding grounds for some birds. Reducing the area of coastal mudflat would make bird feeding grounds smaller, so the number of birds in the Taw Torridge could decline. Some of these birds would find new feeding grounds in other estuaries, but other birds may not: research has shown that the loss of a particular feeding ground can cause the death of birds such as Redshank.

A coastal mudflat

Birds feeding on a mudflat

Oystercatcher

Curlew

Redshank

E

There are different options for the design of tidal barrages, depending on the turbine type, the way in which they are operated and exact location within a particular estuary. Imagine now that three alternative barrage designs are being considered for the Taw Torridge estuary: Barrage A, Barrage B and Barrage C. They all produce the same amount of electricity but the amount of mudflat that would be lost is different for each barrage. The largest area of mudflat would be lost with Barrage A and the least with Barrage C. The amount of mudflat lost with Barrage B is halfway between. The cost of each barrage would also be different and this exercise aims to find out how much you might be willing to pay through your electricity bills for Barrage B or C.

Firstly, please consider Barrage B compared to Barrage A, and assume that:

Barrage A....	**Barrage B....**
  	 
... would result in the loss of 210 hectares of coastal mudflat, which is 42% (almost half) of the total coastal mudflat in the estuary. One hectare (2.5 acres) is about the size of a professional football pitch. ... would produce electricity at the same cost as now, and so would not result in any increase in bills for electricity customers.	... would result in the loss of 140 hectares of coastal mudflat, which is 28% (just over one quarter) of the total coastal mudflat in the estuary. ... would be more expensive to build and operate than Barrage A, so your electricity bills would be higher.

The loss of coastal mudflat with Barrage B would be 70 hectares <u>less</u> than with Barrage A. If Barrage B cost you 50p per year extra on your electricity bill in order to reduce the extent of coastal mudflat loss by 70 hectares, would you be <u>in favour</u> of Barrage B, or <u>not in favour</u> of Barrage B?

F1

How far do you agree or disagree with the following statements?

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
A tidal barrage should not be built in the Taw Torridge estuary under any circumstances	☐	☐	☐	☐	☐
I object to paying higher electricity bills to pay for any tidal barrage	☐	☐	☐	☐	☐
I object to paying higher electricity bills to support any renewable energy development	☐	☐	☐	☐	☐
I cannot afford to pay any more on my electricity bill, however worthy the cause	☐	☐	☐	☐	☐

F2

How far do you agree or disagree with the following statements?

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
I do not want to pay for reducing coastal mudflat loss in the Taw Torridge estuary as I don't go there	☐	☐	☐	☐	☐
A tidal barrage should not be built in the Taw Torridge estuary under any circumstances	☐	☐	☐	☐	☐
I object to paying higher electricity bills to pay for any tidal barrage	☐	☐	☐	☐	☐
I object to paying higher electricity bills to support any renewable energy development	☐	☐	☐	☐	☐
I cannot afford to pay any more on my electricity bill, however worthy the cause	☐	☐	☐	☐	☐

G

Looking at the amounts listed on this card, what is the most you would pay per year to secure Barrage B instead of Barrage A?

Please think carefully about how much you can really afford, and where the additional money would come from, bearing in mind the other things you have to spend your money on.

Additional amount on electricity bill each year	(Approximate equivalent amount per month)
75p	(6p)
£1	(8p)
£1.50	(13p)
£2	(17p)
£2.50	(21p)
£3	(25p)
£3.50	(29p)
£4	(33p)
£4.50	(38p)
£5	(42p)
£6	(50p)
£7	(58p)
£8	(67p)
£9	(75p)
£10	(83p)
£12	(£1.00)
£14	(£1.16)
£16	(£1.33)
£18	(£1.50)
£20	(£1.67)
£25	(£2.10)
£30	(£2.50)
£35	(£2.92)
£40	(£3.33)
£45	(£3.75)
£50	(£4.17)
£60	(£5.00)
£70	(£5.83)
£80	(£6.67)
£90	(£7.50)
£100	(£8.33)
£125	(£10.42)
£150	(£12.50)
£175	(£14.58)
£200	(£16.67)
more than £200	(more than £16.67)

H

Now, please consider Barrage C compared to Barrage A, and assume that:

Barrage A....

... would result in the loss of 210 hectares of coastal mudflat, which is 42% (almost half) of the total coastal mudflat in the estuary. One hectare (2.5 acres) is about the size of a professional football pitch.

... would produce electricity at the same cost as now, and so would not result in any increase in bills for electricity customers.

Barrage C....

... would result in the loss of 70 hectares of coastal mudflat, which is 14% (just over one eighth) of the total coastal mudflat in the estuary.

... would be more expensive to build and operate than Barrage A, so your electricity bills would be higher.

Both barrages still produce the same amount of electricity.

I

The loss of coastal mudflat with Barrage C would be 140 hectares less than with Barrage A. Looking at the amounts listed on this card, what is the most you would pay per year now to have Barrage C instead of Barrage A, and to reduce the extent of coastal mudflat loss by 140 hectares? Bear in mind the other demands on your household budget, and try to give the most realistic answer.

Additional amount on electricity bill each year	(Approximate equivalent amount per month)
75p	(6p)
£1	(8p)
£1.50	(13p)
£2	(17p)
£2.50	(21p)
£3	(25p)
£3.50	(29p)
£4	(33p)
£4.50	(38p)
£5	(42p)
£6	(50p)
£7	(58p)
£8	(67p)
£9	(75p)
£10	(83p)
£12	(£1.00)
£14	(£1.16)
£16	(£1.33)
£18	(£1.50)
£20	(£1.67)
£25	(£2.10)
£30	(£2.50)
£35	(£2.92)
£40	(£3.33)
£45	(£3.75)
£50	(£4.17)
£60	(£5.00)
£70	(£5.83)
£80	(£6.67)
£90	(£7.50)
£100	(£8.33)
£125	(£10.42)
£150	(£12.50)
£175	(£14.58)
£200	(£16.67)
more than £200	(more than £16.67)

J

How far do you agree or disagree with the following statements?

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
Building more wind farms would be better than building tidal barrages, even if this is more costly	☐	☐	☐	☐	☐
Building more nuclear power stations would be better than building tidal barrages, even if this is more costly	☐	☐	☐	☐	☐

We have discussed two particular characteristics of tidal barrages, which are:

Loss of coastal mudflat

The area of coastal mudflat will be reduced if a tidal barrage is built.

Additional cost of electricity each year

The design of the barrage will affect the cost of each unit of electricity produced, which could result in an increase in bills for electricity customers.

The design and location of a barrage can also bring some benefits to the area.
Two of these benefits are:

The number of homes with additional flood protection

Tidal barrages can provide additional flood protection to homes and other buildings in the area upstream of the barrage.

Additional time available for watersports

The time available for recreational activities like sailing, kayaking and other watersports will increase because the tide upstream of the barrage will not go out as far as it would normally, and so there will be deeper water in this area of the estuary for a longer period each day.

1

L

Number of homes with
additional flood protection

Additional time available
for watersports

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Very much more important — *Equal importance* — *Very much more important*

2

Number of homes with
additional flood protection

Loss of
coastal mudflat

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Very much more important — *Equal importance* — *Very much more important*

3

Number of homes with
additional flood protection

Additional cost of
electricity each year

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Very much more important — *Equal importance* — *Very much more important*

M

4

Additional time available
for watersports

Loss of
coastal mudflat

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Very much more important — *Equal importance* — *Very much more important*

5

Additional time available
for watersports

Additional cost of
electricity each year

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Very much more important — *Equal importance* — *Very much more important*

6

Loss of
coastal mudflat

Additional cost of
electricity each year

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Very much more important — *Equal importance* — *Very much more important*

PART V N

Which age group are you in?

a. ☐18-24 b. ☐ 25-34 c. ☐ 35-44 d. ☐ 45-54 e. ☐ 55-64 f. ☐ Above 64

Including yourself, how many people in each of the following age groups currently live in your house year round?

a. Under 18yrs .... b. 18-64yrs .... c. 65 and over ....

Are you:

a. ☐ employed b. ☐ self-employed c. ☐ retired d. ☐ looking after a home full-time
e. ☐ a student f. ☐ temporarily unemployed g. ☐ unable to work due to sickness/disability

What is your approximate annual household income before tax:

a. ☐ Less than £5,000 e. ☐ £35,001 to £45,000 i. ☐ £75,001 to £85,000

b. ☐ £5,001 to £15,000 f. ☐ £45,001 to £55,000 j. ☐ £85,001 to £100,000

c. ☐ £15,001 to £25,000 g. ☐ £55,001 to £65,000 k. ☐ More than £100,000

d. ☐ £25,001 to £35,000 h. ☐ £65,001 to £75,000

Which of the following qualifications do you hold? Please tell the interviewer all that apply.

a. ☐ GCSE or equivalent d. ☐ College/University degree (first or postgraduate)

b. ☐ A level/AS level or equivalent e. ☐ Professional qualification

c. ☐ Diploma/technical qualification

On average, how much has your household been paying each month for electricity bills in the past 12 months? *(Please give your approximate average monthly total throughout the year)*

a. ☐ £0 – £20 d. ☐ £41 – £50 g. ☐ £71 – £80 j. ☐ Above £100

b. ☐ £21 – £30 e. ☐ £51 – £60 h. ☐ £81 – £90 k. ☐ Unsure

c. ☐ £31 – £40 f. ☐ £61 – £70 i. ☐ £91 – £100

Are you a member of any national or local nature conservation organisation (such as the RSPB, a Wildlife Trust, Greenpeace, etc, but excluding the National Trust)?

a. ☐ Yes b. ☐ No

On this card is a list of activities that some people enjoy doing at the by the sea or on rivers. How often do you do any of these in the UK? Please use the scale shown.

	At least once per week	At least once per month	At least once per year	Less than once per year	Never
Walking/cycling on coast or river paths	☐	☐	☐	☐	☐
Watersports (e.g. sailing, surfing, kayaking, outdoor swimming)	☐	☐	☐	☐	☐
Bird watching	☐	☐	☐	☐	☐
Wildfowling (hunting duck & geese)	☐	☐	☐	☐	☐
Recreational angling/crabbing	☐	☐	☐	☐	☐

III. Survey Instruments: Choice Experiment

Survey of Preferences for Tidal Power Generation

Instructions to interviewers:

1. Please read out only the text in *italics* and the questions, which are numbered and shown in **bold** type. All questions should be completed.
2. Questions 1 and 8 do not require a response, but should be filled in by you. These questions for which no response is required are in boxes, and the question text is in normal type.
3. Further instructions at particular points in the questionnaire are shown in CAPITAL LETTERS.
4. There are four sets of choice cards, and each respondent should be asked about one set only (the number of the set used should be entered in question 5). Use Set 1 with the first respondent, Set 2 with the second, and continue rotating the choice sets through the subsequent interviews.

INTRODUCTION

Hello, I'm conducting a survey for the University of Bath and the Plymouth Marine Laboratory about using tidal power to generate electricity in a UK estuary. The questions in the survey aim to find out your attitudes and opinions, and there are no right or wrong answers. The survey is being carried out purely for research purposes. It is entirely confidential, and your survey answers will be anonymous.

The questions take about 15-20 minutes to complete – would you be able to help me with this?

1. Start time:............................

This research is concerned with the possible use of tidal flows in the Taw Torridge estuary to generate electricity.

PART I. ENERGY ISSUES

SHOW CARD A. *The UK Government is looking for alternative ways to produce electricity that do not involve burning fossil fuels: coal, oil and gas. There are two main reasons for this:*

a. Burning fossil fuels produces carbon dioxide, and the Government (along with other Governments and many scientists) believes that carbon dioxide is linked to climate change - a term used to describe increasing global temperature and changing weather patterns.

b. The Government is looking to ensure that the country can maintain a reliable electricity supply into the future, should coal, oil and gas run out or otherwise become difficult to obtain.

2. Looking at the statements about energy issues on this card INDICATE ON CARD A**, to what extent do you agree or disagree with them?**

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree	Don't know
Climate change is a real problem now	☐	☐	☐	☐	☐	☐
Climate change will be a real problem in the future	☐	☐	☐	☐	☐	☐
Burning fossil fuels (coal, oil and gas) is a major cause of climate change	☐	☐	☐	☐	☐	☐
The UK should rely less on imported fuel and produce more energy from sources within its own borders, even if this means electricity bills go up	☐	☐	☐	☐	☐	☐

SHOW CARD B. *One way to reduce fossil fuel use is to generate electricity using sources of energy such as wind, solar, hydroelectric (from rivers), wave energy, tidal current turbines and tidal barrages.* INDICATE EACH RENEWABLE ENERGY PICTURE ON CARD B.

3. On this scale INDICATE ON CARD B, **how well informed do you think you are about using tidal barrages as a source of renewable energy for generating electricity?**

Very well informed	Well informed	Quite well informed	Not very well informed	Not at all informed	Don't know
☐	☐	☐	☐	☐	☐

4. Do you generate any of your own household electricity, for example with solar panels or a wind turbine?

Yes	☐	No	☐

PART II. TIDAL BARRAGES

SHOW CARD C. *The Government is looking at various ways to increase the use of renewable energy to generate electricity because it has set a target to reduce fossil fuel use by 2020. One option which could help to meet this target is building a barrage in the Taw Torridge estuary to generate electricity from tidal flows.*

Two attributes of a tidal barrage are: INDICATE EACH AS YOU READ THE TEXT.

Additional renewable energy

Using a tidal barrage to produce renewable electricity would mean that less fossil fuels are required, so carbon dioxide emissions would be reduced. The scale of this reduction can be thought about in terms of the number of houses that could be powered by the barrage.

Additional cost of electricity each year

The design of the barrage will affect the cost of each unit of electricity produced, which could result in an increase in bills for electricity customers.

A tidal barrage would look something like this. INDICATE BARRAGE PICTURE ON CARD D.

Tidal barrages are not solid dams and do not create lakes upstream – the tide continues to go in and out every day and it is these flows of water that generate electricity. However, the tide upstream of the barrage would not go out as far as it did before. Therefore, construction of a barrage would mean that some area of coastal mudflat would be lost, as it would end up permanently underwater.

Mudflats are important feeding grounds for some birds. INDICATE MUDFLAT PICTURES ON CARD D. *Reducing the area of mudflat would make bird feeding grounds smaller, so the number of birds in the Taw Torridge could decline if a barrage were built. Some of these birds would find new feeding grounds in other estuaries, but other birds may not: research has shown that the loss of a particular feeding ground can cause the death of birds such as Redshank.*

SHOW CARD E. INDICATE MUDFLAT LOSS PICTURE *So, another characteristic of a barrage is:*

Loss of coastal mudflat

The area of coastal mudflat will be reduced if a tidal barrage is built.

The design and location of a tidal barrage can also bring some benefits to the local area. One of these benefits is: INDICATE FLOODING PICTURE AS YOU READ THE TEXT.

The number of homes with additional flood protection

Tidal barrages can provide additional flood protection to homes and other buildings in the area upstream of the barrage.

Imagine now that a number of different tidal barrage designs are being considered for the Taw Torridge estuary. I am now going to ask you to compare some of the proposed schemes, and to choose the one you prefer. You can choose 'neither' if you do not favour either of the barrage options.

Remember that this is a research exercise. It is based on the kind of decisions about energy that are being made but does not reflect an actual plan that is being considered at the moment.

You will be asked to choose between 8 different sets of energy schemes, presented on 8 different cards. In each set, you will need to compare two barrages. The increase in renewable energy, the number of homes given additional flood protection, and the amount of mudflat lost will be different for each of the different options. These factors change because of things like the exact location of the scheme and the design of turbines.

The different options will also result in an increase in the cost per unit of electricity, which would mean an increase in your electricity bills. The amount of this increase will also vary with the different options. This increase is <u>in addition to</u> (not instead of) any other factors that may cause your bill to rise. For the purpose of this exercise, please assume that your electricity bill will rise <u>only</u> as a result of the barrage, and that it will remain at its current level otherwise.

Let's work through an example SHOW CARD F. INDICATE EACH SECTION AS YOU WORK THROUGH IT.

	Barrage A	**Barrage B**	**Neither**
Additional renewable energy (number of homes powered)	21,000	14,500	None
Additional flood protection (number of homes)	1,900	2,400	None
Coastal mudflat lost (hectares)	140 (28% of total)	70 (14% of total)	None
Additional cost of electricity each year due to the barrage	£12 (£1 per month)	£48 (£4 per month)	None
Which option would you choose?	☐	☐	☐

- ***If you choose Barrage A......***
  - *Enough renewable electricity will be produced to power 21,000 homes.*
  - *1,900 homes will have additional flood protection.*
  - *140 hectares of coastal mudflat will be lost, which is 28% (just over one quarter) of the total area of mudflat in the estuary. One hectare (2.5 acres) is about the size of a professional football pitch.*
  - *You would have to pay an additional £12 per year (£1 per month) on your electricity bill.*
- ***If you choose Barrage B......***
  - *Enough renewable electricity will be produced to power 14,500 homes.*
  - *2,400 homes will have additional flood protection.*
  - *70 hectares of coastal mudflat will be lost, which is 14% (just over one eighth) of the total area of coastal mudflat in the estuary.*
  - *You would have to pay an additional £48 per year (£4 per month) on your electricity bill.*
- ***If you choose Neither there would be.....***
  - *No increase in the number of homes powered by renewable electricity.*
  - *No additional flood protection.*
  - *No coastal mudflat will be lost.*
  - *No additional cost of electricity.*

Having considered the different options shown on the card, you need to decide which one you prefer. Please think carefully about how much you can really afford, and where the additional money would come from, bearing in mind the other things you have to spend your money on.

Do you understand the task?

5. For each of the following cards, do you prefer Barrage A, Barrage B or Neither? SHOW CHOICE CARD SET, ONE CARD AT A TIME.

FILL IN THE NUMBER OF THE CARD SET USED.........

	Barrage A	Barrage B	Neither
Card 1	☐	☐	☐
Card 2	☐	☐	☐
Card 3	☐	☐	☐
Card 4	☐	☐	☐
Card 5	☐	☐	☐
Card 6	☐	☐	☐
Card 7	☐	☐	☐
Card 8	☐	☐	☐

IF RESPONDENT CHOOSES 'NEITHER' FOR EVERY CARD, GO TO Q6.
OTHERWISE, GO TO Q7.

6. SHOW CARD G **How far do you agree or disagree with the following statements?**

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree	Don't know
A tidal barrage should not be built in the Taw Torridge estuary under any circumstances	☐	☐	☐	☐	☐	☐
I object to paying higher electricity bills to pay for any tidal barrage	☐	☐	☐	☐	☐	☐
I object to paying higher electricity bills to support any renewable energy development	☐	☐	☐	☐	☐	☐
I cannot afford to pay any more on my electricity bill, however worthy the cause	☐	☐	☐	☐	☐	☐

7. SHOW CARD H **How far do you agree or disagree with the following statements?**

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree	Don't know
Building more wind farms would be better than building tidal barrages, even if this costs me more money	☐	☐	☐	☐	☐	☐
Building more nuclear power stations would be better than building tidal barrages, even if this is more costly to me	☐	☐	☐	☐	☐	☐

PART III. BACKGROUND INFORMATION

In this final section, I would like to collect some more information about you. The questions are not meant to be intrusive, but factors like the size of your household affect the decisions you make. Remember that the survey is anonymous – we will not be able to identify you.

8. Gender: a. ☐ Male b. ☐ Female

9. What is your postcode: _____________

SHOW CARD I (WHICH LISTS QS10-18)

10. Which age group are you in?

a. ☐18-24 b. ☐ 25-34 c. ☐ 35-44 d. ☐ 45-54 e. ☐ 55-64 f. ☐ Above 64

11. Including yourself, how many people in each of the following age groups are currently part of your household year round?

a. Under 18yrs .... b. 18-64yrs .... c. 65 and over ....

12. Are you: a. ☐ employed b. ☐ self-employed c. ☐ retired d. ☐ looking after a home full-time
e. ☐ a student f. ☐ temporarily unemployed g. ☐ unable to work due to sickness or disability

13. What is your approximate total annual household income before tax:

a. ☐ Less than £5,000
b. ☐ £5,001 to £15,000
c. ☐ £15,001 to £25,000
d. ☐ £25,001 to £35,000
e. ☐ £35,001 to £45,000
f. ☐ £45,001 to £55,000
g. ☐ £55,001 to £65,000
h. ☐ £65,001 to £75,000
i. ☐ £75,001 to £85,000
j. ☐ £85,001 to £100,000
k. ☐ More than £100,000
l. ☐ don't know/declined to answer

14. Which of the following qualifications do you have? TICK ALL THAT APPLY.

a. ☐ GCSE or equivalent
b. ☐ A level/AS level or equivalent
c. ☐ Diploma/technical qualification
d. ☐ College/University degree (first or postgraduate)
e. ☐ Professional qualification
f. ☐ No qualifications

15. On average, how much has your household been paying each month for electricity bills in the past 12 months? *(Please give your approximate average monthly total throughout the year)*

a. ☐ £0 – £20
b. ☐ £21 – £30
c. ☐ £31 – £40
d.☐ £41 – £50
e.☐ £51 – £60
f.☐ £61 – £70
g. ☐ £71 – £80
h. ☐ £81 – £90
i. ☐ £91 – £100
j. ☐ Above £100
k. ☐ Unsure

INTERVIEWER INDICATE WHETHER THIS AMOUNT IS:

a. ☐ electricity bill total (actual or estimate)
b. ☐ combined gas & electricity bill total (actual or estimate)
c. ☐ estimate of electricity cost from combined bill

16. Are you a member of any national or local nature conservation organisation (such as the RSPB, a Wildlife Trust, Greenpeace, etc, but excluding the National Trust)?

a. ☐ Yes b. ☐ No

17. Has any home you have lived in, now or in the past, ever flooded?

1. ☐ Yes 2. ☐ No

18. On this card is a list of activities that some people enjoy doing at the by the sea or on rivers. Please could you tell me how often you do any of these in the UK, using the scale shown?

	At least once per week	**At least once per month**	**At least once per year**	**Less than once per year**	**Never**
Watersports (e.g. sailing, surfing, kayaking, outdoor swimming)	☐	☐	☐	☐	☐
Walking/cycling on coast or river paths	☐	☐	☐	☐	☐
Bird watching	☐	☐	☐	☐	☐
Wildfowling (hunting duck & geese)	☐	☐	☐	☐	☐
Recreational angling/crabbing	☐	☐	☐	☐	☐

PART IV. TO BE COMPLETED BY THE INTERVIEWER

19. Survey end time ....

20. Do you think the respondent understood the valuation exercise?

1. ☐ Yes   2. ☐ No

21. On a scale of 1 (very easy) to 5 (very difficult), how difficult do you think it was for the respondent to complete the valuation exercise?

Very easy				**Very difficult**
1	2	3	4	5
☐	☐	☐	☐	☐

22. On a scale of 1 (not at all annoyed) to 5 (very annoyed), how annoyed do you think the respondent was by the survey?

Not at all annoyed				**Very annoyed**
1	2	3	4	5
☐	☐	☐	☐	☐

23. In the event that the respondent stopped the survey, do you think that the respondent:

☐ Did not understand the survey

☐ Was annoyed by the survey

☐ Was annoyed by the length of the survey

☐ Other..

24. General comments on the interview (if any):

....

....

....

....

....

....

....

25. Survey type: In house ☐ Door step ☐ Street ☐

26. Survey site: ....

27. Weather: ....

28. Interviewer: ....

29. Date: ....

PART I | A

The UK Government is looking for alternative ways to produce electricity that do not involve burning fossil fuels (coal, oil and gas). There are two main reasons for this:

1) Burning fossil fuels produces carbon dioxide, and the Government (along with other Governments and many scientists) believes that carbon dioxide is linked to climate change - a term used to describe increasing global temperature and changing weather patterns.
2) The Government is looking to ensure that the country can maintain a reliable electricity supply into the future, should coal, oil and gas run out or otherwise become difficult to obtain.

Looking at the statements about energy issues on this card, to what extent do you agree or disagree with them?

	Strongly agree	**Agree**	**Neither agree nor disagree**	**Disagree**	**Strongly disagree**
Climate change is a real problem now	☐	☐	☐	☐	☐
Climate change will be a real problem in the future	☐	☐	☐	☐	☐
Burning fossil fuels (coal, oil and gas) is a major cause of climate change	☐	☐	☐	☐	☐
The UK should rely less on imported fuel and produce more energy from sources within its own borders, even if this means electricity bills go up	☐	☐	☐	☐	☐

B

One way to reduce fossil fuel use is to generate electricity using sources of energy such as:


wind


solar


hydroelectric (from rivers)


wave


tidal current turbine


tidal barrage

Using the scale below, how well informed do you think you are about using tidal barrages for generating renewable electricity?

- Very well informed
- Well informed
- Quite well informed
- Not very well informed
- Not at all informed

The Government is looking at various ways to increase the use of renewable energy to generate electricity because it has set a target to reduce fossil fuel use by 2020. One option which could help to meet this target is building a barrage in the Taw Torridge estuary to generate electricity from tidal flows.

Two attributes of a tidal barrage design are the:

Additional renewable energy

Using a tidal barrage to produce renewable electricity would mean that less fossil fuels are required, so carbon dioxide emissions would be reduced. The scale of this reduction can be thought about in terms of the number of houses that could be powered by the barrage.

Additional cost of electricity each year

The design of the barrage will affect the cost of each unit of electricity produced, which could result in an increase in bills for electricity customers.

D

A tidal barrage would look something like this:

Tidal barrages are not solid dams and do not create lakes upstream – the tide continues to go in and out every day and it is these flows of water that generate electricity. However, the tide upstream of the barrage would not go out as far as it did before. Therefore, construction of the barrage would mean that some area of coastal mudflat would be lost, as it would end up permanently underwater.

Mudflats are important feeding grounds for some birds. Reducing the area of coastal mudflat would make bird feeding grounds smaller, so the number of birds in the Taw Torridge could decline. Some of these birds would find new feeding grounds in other estuaries, but other birds may not: research has shown that the loss of a particular feeding ground can cause the death of birds such as Redshank.

A coastal mudflat

Birds feeding on a mudflat

Oystercatcher

Curlew

Redshank

E

So another characteristic of a barrage is:

Loss of coastal mudflat

The area of coastal mudflat will be reduced if a tidal barrage is built.

The design and location of a barrage can also bring some benefits to the area. One of these benefits is:

The number of homes with additional flood protection

Tidal barrages can provide additional flood protection to homes and other buildings in the area upstream of the barrage.

Imagine now that a number of different tidal barrage designs are being considered for the Taw Torridge estuary. You will be asked to compare some of the proposed schemes, and to choose the one you prefer. You can choose 'neither' if you do not favour either of the barrage options.

Remember that this is a research exercise. It is based on the kind of decisions about energy that are being made but does not reflect an actual plan that is being considered at the moment.

You will be asked to choose between 8 different sets of energy schemes, presented on 8 different cards. In each set, you will need to compare two barrages. The increase in renewable energy, the number of homes given additional flood protection, and the amount of mudflat lost will be different for each of the different options. These factors change because of things like the exact location of the scheme and the design of turbines.

The different options will also result in an increase in the cost per unit of electricity, which would mean an increase in your electricity bills. The amount of this increase will also vary with the different options. This increase is in addition to (not instead of) any other factors that may cause your bill to rise. For the purpose of this exercise, please assume that your electricity bill will rise only as a result of the barrage, and that it will remain at its current level otherwise.

An example of a choice card: F

	Barrage A	**Barrage B**	**Neither**
Additional renewable energy (number of homes powered)	 21,000	 14,500	None
Additional flood protection (number of homes)	 1,900	 2,400	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	 140 (28%)	 70 (14%)	None
Additional cost of electricity each year due to the barrage	£12 (£1 per month)	£48 (£4 per month)	None
Which option would you choose?	☐	☐	☐

- **If you choose Barrage A......**
  - Enough renewable electricity will be produced to power 21,000 homes.
  - 1,900 homes will have additional flood protection.
  - 140 hectares of coastal mudflat will be lost, which is 28% (just over one quarter) of the total area of mudflat in the estuary. One hectare (2.5 acres) is about the size of a professional football pitch.
  - You would have to pay an additional £12 per year (£1 per month) on your electricity bill.
- **If you choose Barrage B......**
  - Enough renewable electricity will be produced to power 14,500 homes.
  - 2,400 homes will have additional flood protection.
  - 70 hectares of coastal mudflat will be lost, which is 14% (just over one eighth) of the total area of coastal mudflat in the estuary.
  - You would have to pay an additional £48 per year (£4 per month) on your electricity bill.
- **If you choose Neither there would be.....**
  - No increase in the number of homes powered by renewable electricity.
  - No additional flood protection.
  - No coastal mudflat will be lost.
  - No additional cost of electricity.

Having considered the different options shown on the card, you need to decide which one you prefer. Please think carefully about how much you can really afford, and where the additional money would come from, bearing in mind the other things you have to spend your money on.

G

How far do you agree or disagree with the following statements?

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
A tidal barrage should not be built in the Taw Torridge estuary under any circumstances	☐	☐	☐	☐	☐
I object to paying higher electricity bills to pay for any tidal barrage	☐	☐	☐	☐	☐
I object to paying higher electricity bills to support any renewable energy development	☐	☐	☐	☐	☐
I cannot afford to pay any more on my electricity bill, however worthy the cause	☐	☐	☐	☐	☐

H

How far do you agree or disagree with the following statements?

	Strongly agree	**Agree**	**Neither agree nor disagree**	**Disagree**	**Strongly disagree**
Building more wind farms would be better than building tidal barrages, even if this is more costly	☐	☐	☐	☐	☐
Building more nuclear power stations would be better than building tidal barrages, even if this is more costly	☐	☐	☐	☐	☐

PART III | I

Which age group are you in?

a. ☐18-24 b. ☐ 25-34 c. ☐ 35-44 d. ☐ 45-54 e. ☐ 55-64 f. ☐ Above 64

Including yourself, how many people in each of the following age groups currently live in your house year round?

a. Under 18yrs .... b. 18-64yrs .... c. 65 and over ....

Are you:

a. ☐ employed b. ☐ self-employed c. ☐ retired d. ☐ looking after a home full-time
e. ☐ a student f. ☐ temporarily unemployed g. ☐ unable to work due to sickness/disability

What is your approximate annual household income before tax:

a. ☐ Less than £5,000 e. ☐ £35,001 to £45,000 i. ☐ £75,001 to £85,000
b. ☐ £5,001 to £15,000 f. ☐ £45,001 to £55,000 j. ☐ £85,001 to £100,000
c. ☐ £15,001 to £25,000 g. ☐ £55,001 to £65,000 k. ☐ More than £100,000
d. ☐ £25,001 to £35,000 h. ☐ £65,001 to £75,000

Which of the following qualifications do you hold? Please tell the interviewer all that apply.

a. ☐ GCSE or equivalent d. ☐ College/University degree (first or postgraduate)
b. ☐ A level/AS level or equivalent e. ☐ Professional qualification
c. ☐ Diploma/technical qualification

On average, how much has your household been paying each month for electricity bills in the past 12 months? *(Please give your approximate average monthly total throughout the year)*

a. ☐ £0 – £20 d. ☐ £41 – £50 g. ☐ £71 – £80 j. ☐ Above £100
b. ☐ £21 – £30 e. ☐ £51 – £60 h. ☐ £81 – £90 k. ☐ Unsure
c. ☐ £31 – £40 f. ☐ £61 – £70 i. ☐ £91 – £100

Are you a member of any national or local nature conservation organisation (such as the RSPB, a Wildlife Trust, Greenpeace, etc, but excluding the National Trust)?

a. ☐ Yes b. ☐ No

On this card is a list of activities that some people enjoy doing at the by the sea or on rivers. How often do you do any of these in the UK? Please use the scale shown.

	At least once per week	At least once per month	At least once per year	Less than once per year	Never
Walking/cycling on coast or river paths	☐	☐	☐	☐	☐
Watersports (e.g. sailing, surfing, kayaking, outdoor swimming)	☐	☐	☐	☐	☐
Bird watching	☐	☐	☐	☐	☐
Wildfowling (hunting duck & geese)	☐	☐	☐	☐	☐
Recreational angling/crabbing	☐	☐	☐	☐	☐

Choice cards

SET 1. Card 1

	Barrage A	**Barrage B**	**Neither**
Additional renewable energy (number of homes powered)	 21,000	 14,500	None
Additional flood protection (number of homes)	 1,900	 2,400	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	 70 (14%)	 140 (28%)	None
Additional cost of electricity each year due to the barrage	£3 (25p per month)	£12 (£1 per month)	None
Which option would you choose?	☐	☐	☐

SET 1. Card 2

	Barrage A	**Barrage B**	**Neither**
Additional renewable energy (number of homes powered)	 21,000	 14,500	None
Additional flood protection (number of homes)	 1,900	 2,400	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	 140 (28%)	 70 (14%)	None
Additional cost of electricity each year due to the barrage	£12 (£1 per month)	£48 (£4 per month)	None
Which option would you choose?	☐	☐	☐

SET 1. Card 3

	Barrage A	Barrage B	Neither
Additional renewable energy (number of homes powered)	 14,500	 21,000	None
Additional flood protection (number of homes)	 1,900	 2,400	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	 70 (14%)	 140 (28%)	None
Additional cost of electricity each year due to the barrage	£48 (£4 per month)	£192 (£16 per month)	None
Which option would you choose?	☐	☐	☐

SET 1. Card 4

	Barrage A	Barrage B	Neither
Additional renewable energy (number of homes powered)	 14,500	 21,000	None
Additional flood protection (number of homes)	 1,900	 2,400	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	 140 (28%)	 70 (14%)	None
Additional cost of electricity each year due to the barrage	£192 (£16 per month)	£3 (25p per month)	None
Which option would you choose?	☐	☐	☐

SET 1. Card 5

	Barrage A	Barrage B	Neither
Additional renewable energy (number of homes powered)	 14,500	 21,000	None
Additional flood protection (number of homes)	 2,400	 1,900	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	 140 (28%)	 70 (14%)	None
Additional cost of electricity each year due to the barrage	£48 (£4 per month)	£192 (£16 per month)	None
Which option would you choose?	☐	☐	☐

SET 1. Card 6

	Barrage A	Barrage B	Neither
Additional renewable energy (number of homes powered)	 14,500	 21,000	None
Additional flood protection (number of homes)	 2,400	 1,900	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	 70 (14%)	 140 (28%)	None
Additional cost of electricity each year due to the barrage	£12 (£1 per month)	£48 (£4 per month)	None
Which option would you choose?	☐	☐	☐

SET 1. Card 7

	Barrage A	**Barrage B**	**Neither**
Additional renewable energy (number of homes powered)	 21,000	 14,500	None
Additional flood protection (number of homes)	 2,400	 1,900	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	 140 (28%)	 70 (14%)	None
Additional cost of electricity each year due to the barrage	£ £3 (25p per month)	£ £12 (£1 per month)	None
Which option would you choose?	☐	☐	☐

SET 1. Card 8

	Barrage A	**Barrage B**	**Neither**
Additional renewable energy (number of homes powered)	 21,000	 14,500	None
Additional flood protection (number of homes)	 2,400	 1,900	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	 70 (14%)	 140 (28%)	None
Additional cost of electricity each year due to the barrage	£ £192 (£16 per month)	£ £3 (25p per month)	None
Which option would you choose?	☐	☐	☐

SET 2. Card 1

	Barrage A	Barrage B	Neither
Additional renewable energy (number of homes powered)	 21,000	 14,500	None
Additional flood protection (number of homes)	 1,900	 2,400	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	 70 (14%)	 140 (28%)	None
Additional cost of electricity each year due to the barrage	£12 (£1 per month)	£48 (£4 per month)	None
Which option would you choose?	☐	☐	☐

SET 2. Card 2

	Barrage A	Barrage B	Neither
Additional renewable energy (number of homes powered)	 21,000	 14,500	None
Additional flood protection (number of homes)	 1,900	 2,400	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	 140 (28%)	 70 (14%)	None
Additional cost of electricity each year due to the barrage	£48 (£4 per month)	£192 (£16 per month)	None
Which option would you choose?	☐	☐	☐

SET 2. Card 3

	Barrage A	Barrage B	Neither
Additional renewable energy (number of homes powered)	14,500	21,000	None
Additional flood protection (number of homes)	1,900	2,400	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	70 (14%)	140 (28%)	None
Additional cost of electricity each year due to the barrage	£192 (£16 per month)	£3 (25p per month)	None
Which option would you choose?	☐	☐	☐

SET 2. Card 4

	Barrage A	Barrage B	Neither
Additional renewable energy (number of homes powered)	14,500	21,000	None
Additional flood protection (number of homes)	1,900	2,400	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	140 (28%)	70 (14%)	None
Additional cost of electricity each year due to the barrage	£3 (25p per month)	£12 (£1 per month)	None
Which option would you choose?	☐	☐	☐

SET 2. Card 5

	Barrage A	Barrage B	Neither
Additional renewable energy (number of homes powered)	 14,500	 21,000	None
Additional flood protection (number of homes)	 2,400	 1,900	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	 140 (28%)	 70 (14%)	None
Additional cost of electricity each year due to the barrage	£192 (£16 per month)	£3 (25p per month)	None
Which option would you choose?	☐	☐	☐

SET 2. Card 6

	Barrage A	Barrage B	Neither
Additional renewable energy (number of homes powered)	 14,500	 21,000	None
Additional flood protection (number of homes)	 2,400	 1,900	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	 70 (14%)	 140 (28%)	None
Additional cost of electricity each year due to the barrage	£48 (£4 per month)	£192 (£16 per month)	None
Which option would you choose?	☐	☐	☐

SET 2. Card 7

	Barrage A	Barrage B	Neither
Additional renewable energy (number of homes powered)	21,000	14,500	None
Additional flood protection (number of homes)	2,400	1,900	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	140 (28%)	70 (14%)	None
Additional cost of electricity each year due to the barrage	£12 (£1 per month)	£48 (£4 per month)	None
Which option would you choose?	☐	☐	☐

SET 2. Card 8

	Barrage A	Barrage B	Neither
Additional renewable energy (number of homes powered)	21,000	14,500	None
Additional flood protection (number of homes)	2,400	1,900	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	70 (14%)	140 (28%)	None
Additional cost of electricity each year due to the barrage	£3 (25p per month)	£12 (£1 per month)	None
Which option would you choose?	☐	☐	☐

SET 3. Card 1

	Barrage A	Barrage B	Neither
Additional renewable energy (number of homes powered)	 21,000	 14,500	None
Additional flood protection (number of homes)	 1,900	 2,400	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	 70 (14%)	 140 (28%)	None
Additional cost of electricity each year due to the barrage	 £48 (£4 per month)	 £192 (£16 per month)	None
Which option would you choose?	☐	☐	☐

SET 3. Card 2

	Barrage A	Barrage B	Neither
Additional renewable energy (number of homes powered)	 21,000	 14,500	None
Additional flood protection (number of homes)	 1,900	 2,400	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	 140 (28%)	 70 (14%)	None
Additional cost of electricity each year due to the barrage	 £192 (£16 per month)	 £3 (25p per month)	None
Which option would you choose?	☐	☐	☐

SET 3. Card 3

	Barrage A	**Barrage B**	**Neither**
Additional renewable energy (number of homes powered)	14,500	21,000	None
Additional flood protection (number of homes)	1,900	2,400	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	70 (14%)	140 (28%)	None
Additional cost of electricity each year due to the barrage	£3 (25p per month)	£12 (£1 per month)	None
Which option would you choose?	☐	☐	☐

SET 3. Card 4

	Barrage A	**Barrage B**	**Neither**
Additional renewable energy (number of homes powered)	14,500	21,000	None
Additional flood protection (number of homes)	1,900	2,400	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	140 (28%)	70 (14%)	None
Additional cost of electricity each year due to the barrage	£12 (£1 per month)	£48 (£4 per month)	None
Which option would you choose?	☐	☐	☐

SET 3. Card 5

	Barrage A	Barrage B	Neither
Additional renewable energy (number of homes powered)	 14,500	 21,000	None
Additional flood protection (number of homes)	 2,400	 1,900	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	 140 (28%)	 70 (14%)	None
Additional cost of electricity each year due to the barrage	£3 (25p per month)	£12 (£1 per month)	None
Which option would you choose?	☐	☐	☐

SET 3. Card 6

	Barrage A	Barrage B	Neither
Additional renewable energy (number of homes powered)	 14,500	 21,000	None
Additional flood protection (number of homes)	 2,400	 1,900	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	 70 (14%)	 140 (28%)	None
Additional cost of electricity each year due to the barrage	£192 (£16 per month)	£3 (25p per month)	None
Which option would you choose?	☐	☐	☐

SET 3. Card 7

	Barrage A	Barrage B	Neither
Additional renewable energy (number of homes powered)	21,000	14,500	None
Additional flood protection (number of homes)	2,400	1,900	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	140 (28%)	70 (14%)	None
Additional cost of electricity each year due to the barrage	£48 (£4 per month)	£192 (£16 per month)	None
Which option would you choose?	☐	☐	☐

SET 3. Card 8

	Barrage A	Barrage B	Neither
Additional renewable energy (number of homes powered)	21,000	14,500	None
Additional flood protection (number of homes)	2,400	1,900	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	70 (14%)	140 (28%)	None
Additional cost of electricity each year due to the barrage	£12 (£1 per month)	£48 (£4 per month)	None
Which option would you choose?	☐	☐	☐

SET 4. Card 1

	Barrage A	**Barrage B**	**Neither**
Additional renewable energy (number of homes powered)	 21,000	 14,500	None
Additional flood protection (number of homes)	 1,900	 2,400	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	 70 (14%)	 140 (28%)	None
Additional cost of electricity each year due to the barrage	£192 (£16 per month)	£3 (25p per month)	None
Which option would you choose?	☐	☐	☐

SET 4. Card 2

	Barrage A	**Barrage B**	**Neither**
Additional renewable energy (number of homes powered)	 21,000	 14,500	None
Additional flood protection (number of homes)	 1,900	 2,400	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	 140 (28%)	 70 (14%)	None
Additional cost of electricity each year due to the barrage	£3 (25p per month)	£12 (£1 per month)	None
Which option would you choose?	☐	☐	☐

SET 4. Card 3

	Barrage A	**Barrage B**	**Neither**
Additional renewable energy (number of homes powered)	 14,500	 21,000	None
Additional flood protection (number of homes)	 1,900	 2,400	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	 70 (14%)	 140 (28%)	None
Additional cost of electricity each year due to the barrage	£ £12 (£1 per month)	£ £48 (£4 per month)	None
Which option would you choose?	☐	☐	☐

SET 4. Card 4

	Barrage A	**Barrage B**	**Neither**
Additional renewable energy (number of homes powered)	 14,500	 21,000	None
Additional flood protection (number of homes)	 1,900	 2,400	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	 140 (28%)	 70 (14%)	None
Additional cost of electricity each year due to the barrage	£ £48 (£4 per month)	£ £192 (£16 per month)	None
Which option would you choose?	☐	☐	☐

SET 4. Card 5

	Barrage A	Barrage B	Neither
Additional renewable energy (number of homes powered)	 14,500	 21,000	None
Additional flood protection (number of homes)	 2,400	 1,900	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	 140 (28%)	 70 (14%)	None
Additional cost of electricity each year due to the barrage	 £12 (£1 per month)	 £48 (£4 per month)	None
Which option would you choose?	☐	☐	☐

SET 4. Card 6

	Barrage A	Barrage B	Neither
Additional renewable energy (number of homes powered)	 14,500	 21,000	None
Additional flood protection (number of homes)	 2,400	 1,900	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	 70 (14%)	 140 (28%)	None
Additional cost of electricity each year due to the barrage	 £3 (25p per month)	 £12 (£1 per month)	None
Which option would you choose?	☐	☐	☐

SET 4. Card 7

	Barrage A	Barrage B	Neither
Additional renewable energy (number of homes powered)	 21,000	 14,500	None
Additional flood protection (number of homes)	 2,400	 1,900	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	 140 (28%)	 70 (14%)	None
Additional cost of electricity each year due to the barrage	£192 (£16 per month)	£3 (25p per month)	None
Which option would you choose?	☐	☐	☐

SET 4. Card 8

	Barrage A	Barrage B	Neither
Additional renewable energy (number of homes powered)	 21,000	 14,500	None
Additional flood protection (number of homes)	 2,400	 1,900	None
Coastal mudflat lost (hectares) *(One hectare is about the size of a professional football pitch)*	 70 (14%)	 140 (28%)	None
Additional cost of electricity each year due to the barrage	£48 (£4 per month)	£192 (£16 per month)	None
Which option would you choose?	☐	☐	☐